Bernard Vanlauwe · Piet van Asten
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Challenges and Opportunities for Agricultural Intensification of the Humid Highland Systems of Sub-Saharan Africa

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Introduction

An International Conference on 'Challenges and opportunities for agricultural intensification of the humid highland systems of sub-Saharan Africa' was organized by the Consortium for Improving Agricultural Livelihoods in Central Africa in October 2011 in Rwanda. CIALCA had been operating in the Central African highlands for over 6 years and felt that the time was opportune to exchange experiences with a wider group of research and development organizations aiming at intensifying African smallholder agriculture.

The Conference was organized around four major themes:

1. System components: Farming systems consist of different units including crop and livestock ventures and the total farm productivity, ecosystem service provision, and ultimately farmers' well-being depend on the performance of each of these components. Most components have specific constraints that prevent them from reaching their potential productivity, and addressing these through site- and farmer-specific interventions is crucial to improving rural livelihoods.
2. System integration: Components of farming systems interact with one another and with common property resources, especially in environments where production resources are in short supply. Trade-offs are common between investments in specific system components and particularly for farming households that are less resource-endowed. Models for farming system analysis are important tools for analyzing trade-offs and exploring profitable scenarios for the intensification of farming systems.
3. Drivers and determinants for adoption: The adoption of strategies for increased farm-level productivity often requires specific enabling conditions. Such drivers and determinants may operate at different scales and affect specific system components. A clear understanding of those drivers is important to determine adaptive strategies that can contribute to the intensification of important farming systems and prioritize development-oriented investment and policy needs.
4. Knowledge-intensive approaches: System approaches and interventions are often knowledge-intensive and therefore specific dissemination approaches are needed. This is especially relevant for areas with relatively low levels of literacy

and formal education. The identification of simple, fast-track interventions that can be disseminated within the lifetime of most projects is needed within the context of more knowledge-intensive approaches. Tensions exist between knowledge-intensive approaches and the need to reach many households.

Based on the various keynote and other oral presentations, the poster presentations, and the panel discussions organized around the four major themes of the Conference, the following general conclusions and lessons learnt were adopted by the participants.

Agro-ecological Intensification: Conflicting Concepts for a Generally Accepted Need

- Growth in agricultural production and productivity is necessary but not sufficient for global food security. Future food security strategies include: (a) reducing demand, (b) filling the production shortfall and (c) avoiding losses of productive capacity.
- A medium and long-term, holistic, multifunctional and systemic view is required in addressing the challenges and aim at treating the causes of low soil productivity, not the symptoms, while ensuring that farmers have short-term benefits as a result of any system change.
- Subsidies (e.g. vouchers) and handouts are just one option to facilitate the adoption of new technologies, mainly to raise awareness and to make these technologies affordable to smallholder farmers. Subsidies (1) should be part of a package for better use efficiency, including technical support, business support, market development, institutional development, and facilitation by local organizations and (2) should not be used to push technologies that are not relevant for and/or adapted to local conditions and specific farmers' needs.

Technology Components for Integration in Agro-ecological Intensification Pathways

- Increased productivity will require investments in nutrients to improve and sustain soil fertility. ISFM offers technologies for managing organic inputs and the efficient use of mineral fertilizers with minimal environmental risks. Successful ISFM interventions must consider trade-offs in the use of labour, also in financial and nutrient resources.
- Difficulty in getting access to mineral fertilizers is a constraint in many areas of East and Central Africa. The availability of mineral fertilizer needs to be improved for unit costs to be reduced (and made affordable to farmers). Benefits of scale of mineral fertilizer availability are needed if the intensification of farming systems is to be achieved.

- Demonstration to farmers that quality seeds provide better yields and that this translates into profit is essential. Market dynamics can provide a commercial pull for improved seeds. Opportunities exist for investing in the multiplication of improved legume and banana varieties at the community-level but, especially for banana, quality assurance is critical.

Integration of Technical Components at the Farming System Level

- Smallholder farming systems are diverse, spatially heterogeneous and highly dynamic. The integrated analysis of farming systems allows the implications of proposed technologies to be studied across spatial and temporal scales. The integration of legumes into systems and the appropriate allocation of fertilizer need to be based on the identification of "best-fit" interventions, selected from a "basket of best-bet options".
- Different types of innovations need to be identified for different types of farmers. (1) Agricultural labourers: how can labour-intensive agriculture be enhanced? (2) Subsistence farmers: how can risk-reducing agricultural techniques be facilitated? (3) Farmers with surplus potential: how can productive agriculture and market access be enhanced? (4) Farmers with large surpluses: how can we make sure that innovations result in trickle-down effects to the farming community?
- Intercrop systems can increase efficiencies at the farm level, e.g., returns to land, labour and fertilizer. Climate-smart systems can use intercropping to combine adaptation to and mitigation of the effects (e.g., coffee–banana systems)
- The role of livestock as a driver for agro-ecological intensification needs to be exploited. The 'livestock ladder' concept provides a framework to allow an exit from poverty and improve nutrition for poor crop-livestock farmers.

Drivers and Pathways for Achieving Impact

- Adoption is influenced by the farmers' perception of the attributes of a technology, capital constraints and institutional support. Social networks and participation in technology evaluation are strong drivers of adoption. A mix of underlying challenges calls for a mix of interventions for different categories of farmers, and the acknowledgment that there is not a 'one size fits all' set of interventions.
- Grain legumes can be important in smallholder farmers' strategies for income, food security, nutrition, natural resource management (NRM) and gender equity but such interventions are best integrated along effective value chains. It is important to enhance the nutritional diversity of farming systems, based on system diversification, including the diversity of locally important crops.

- Community-based organizations need to be included in agricultural extension efforts. Relay organizations can successfully diffuse innovations to farmers' groups, although continuous training and financial sustainability are crucial. Farmers need to be equipped with simple decision support tools to aid them in making decisions on various strategies for resource allocation.
- Evaluating the impact of new technologies requires a mix of technical studies, on-farm adaptive research, and approaches to learn from the site-specific responses of a specific technology. Socio-economic studies should use state-of-the-art methodology, including randomized control trials, aiming at addressing causality.

Approaches for Effective Communication on Intensification Options

- Agro-ecological intensification and impact accountability are driving an integration of research and extension which may lead to a better translation of research outputs into development outcomes.
- Agricultural stakeholders need to consider farmers' socio-economic context in designing extension intervention strategies. The success or failure of an intervention is also dependent on local social structures where traditional institutions may play an important role in interventions and scaling up.
- Innovation platforms are important for relevant, efficient and effective partnerships across various stakeholders' groups. Planning of impact pathways is a necessity from the start. When farmers' priorities are given due consideration (e.g., domestic water availability), their interest in NRM increases.
- Due to the heterogeneity and complexity of smallholder farming systems, local adaptation/farm typologies in scalability needs to be integrated in dissemination approaches, partly building on the Genotype × Environment × Management equation. Specific communication channels should be tailored to the specific technologies being promoted.

This book of proceedings presents papers submitted by participants who made oral presentations at the Conference and which were accepted for publication by the Scientific Committee. We hope that the papers presented in this book will advance the science of sustainable intensification with a specific focus on the humid highlands of sub-Saharan Africa.

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Part I
System Characterization

Chapter 1
Bridging the Soil Map of Rwanda with the 'Farmer's Mental Soil Map' for an Effective Integrated and Participatory Watershed Management Research Model

P.N. Rushemuka, J.P. Bizimana, J.J.M. Mbonigaba, and L. Bock

Abstract Rwanda has a digital land resource database including a soil map at 1:50,000. The usefulness and use of this map in agricultural research and extension at watershed level are limited by the medium scale and the language of *Soil Taxonomy* to those non-specialists in soil science that the map is intended to serve. Therefore, since its completion, the soil map of Rwanda has been a 'sleeping beauty'. Meanwhile, farmers have a deep knowledge of their soils that they identify each soil series that needs to be described and have a simple name for each of them, just, as they have for trees, crops or animals: in their own frame of reference for soils, they have a '*precise and accurate mental soil map*'. It is now recognized that, for development purposes, especially when working with small farmers, the farmers' soil knowledge is a much better starting point than the international classification systems. A methodological approach was developed to bridge the gap between the soil map of Rwanda and the farmers' 'mental soil map'. Results show that with the same watershed (1) the land units (2) the diagnostic horizons of the farmers' soil types and (3) geographic coordinates are useful means of relating an existing soil map database with the farmers' soil knowledge. Linking the two knowledge systems in this way will enable scientists to introduce new soil-related technologies as a part of the farmers' soil knowledge perspectives during the participatory planning and implementation of development projects.

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Keywords Soil map • *Soil Taxonomy* • Participatory Integrated Watershed Management (PIWM) • Farmers' soil knowledge • Rwanda

Introduction

Crop performance varies from field to field because of changing soil characteristics (Papadakis 1975; Drechsel et al. 1996; Steiner 1998; Tittonell et al. 2007; Giller et al. 2011). This variability is influenced by factors of both soil type and land use (Genot et al. 2007; Tittonell et al. 2007; Zingore et al. 2007). In soil-related agricultural research, extension recommendations are relevant to farmers only if they take into account these factors of variability in soil characteristics (Laker 1981; Steiner 1998; Fairhurst 2012). It is in this framework that Rwanda has acquired a digital land resource database including a medium-scale (1:50,000) soil map (Birasa et al. 1990; MINAGRI 2002). Although the availability of such a soil map would revolutionize soil-related agricultural research and extension behaviour by making soil-specific interventions possible, paradoxically, soil-related agricultural research and extension activities are still implemented without reference to the soil factor. Thus, the soil map of Rwanda (CPR: for Carte Pédologique du Rwanda) has joined other soil maps of developing countries in being one of the 'sleeping beauties' (Cline 1981). In these circumstances, only generic/blanket recommendations are formulated to cover broader areas with diverse soil types (Sanchez et al. 1997). Therefore, farmers lack the precise recommendations for their specific soil types (Steiner 1998). This situation makes interventions such as the response of crops to fertilizers more erratic and less profitable (Rutunga 1991; Sanchez et al. 1997): hence the low adoption of promoted technologies. The use and usefulness of this soil map to those non-specialists in soil survey that the map intends to serve are limited by the Soil Taxonomy language and the medium scale, among other constraints. Meanwhile, farmers identify each soil type that needs to be described and have a simple name, easily intelligible, for each of them, just as they have for trees or animal species. In addition, even if the fact is ignored by many scientists and most of extensionists, farmers have quite a good idea of the spatial distribution of soils in the landscape and exploit the difference in soils during soil fertility management practices. Some authors use the term 'precise and accurate mental soil map' (Barrera-Bassols et al. 2006). In their low input system, they practise 'precision agriculture' (Barrios et al. 2006; Barrera-Bassols et al. 2006). Thus, one way of solving the problem of how to recommend soil-specific interventions, especially when working with small farmers, is to tailor the technical soil fertility management interventions to the farmers' frame of reference of soils (Thomasson 1981; Niemeijer and Mazzucato 2003; Dawoe et al. 2012).

In Rwanda, two main international classification systems have been used. A former Belgian classification for Congo-Rwanda and Burundi, (Institut National d'Etudes Agronomiques au Congo – INEAC) was introduced in the 1950s (Van Wambeke 1963). A small-scale (1:250,000) soil association map has been produced (Prioul and Sirven 1981). The 1990s (1980–1990) coincided with the CPR project which introduced the *Soil Taxonomy*. The CPR project released a medium-scale (1:50,000) digital soil map (Birasa et al. 1990; MINAGRI 2002). In the meantime, farmers have maintained their own system of soil nomenclature. However, in Rwanda, all three classification systems have remained mysterious to most agricultural researchers and extensionists, including ‘soil scientists’. The fact that information (both technical and indigenous) on the soil resource has been overlooked in practical agriculture of many sub-Saharan Africa countries might be the origin of many myths surrounding fertilizer use in this region as they have been denounced by Vanlauwe and Giller (2006). It might also provide an explanation for the controversial debates about fertilizer use observed at various international conferences in the region. Therefore, we argue that communication in the agricultural research and extension domains suffers from the inaccessibility of the international soil classification systems and the disregard of the farmers’ soil knowledge and the gap that exists between the two knowledge systems. The objective of this study was to demystify the soil maps by overcoming the communication barriers imposed by the pedo-taxonomic jargon of the soil map of Rwanda, thereby demonstrating that soil classification systems are not magic things: they refer to soils cultivated by local farmers which have already user friendly local names. Therefore, what is complicated seems not to be an understanding of the soil but of the technical soil knowledge system (see Wielemeker et al. 2001; Bui 2004). The interest of such a study is that, during the Participatory Integrated Watershed Management innovation model, soil scientists – and scientists in other disciplines– can use the farmers’ frame of reference of soils and farmers’ soil nomenclature while staying connected to the technical soil resource information to introduce new technologies, such as optimal fertilizer application and adapted crop varieties, in the right way.

Methodological Approach and Study Area

The watershed/catchment was chosen as an appropriate geographic scope for understanding the spatial distribution of soils in both knowledge systems. The technical knowledge was captured through the analysis of different legends of the CPR and the soil properties of various soil series of this soil map. Farmers’ knowledge was gathered by making a list of farmers’ soil types followed by linguistic analysis/ethno-semantic elucidation (Niemeijer and Mazzucato 2003). More insights were gained by means of integrated toposequence analysis coupled with iterative focus group discussions and individual conversations (Gobin et al. 2000). The communication bridges were established between the technical and farmers’ soil names by means of the land units where soils occurs, diagnostic horizons of the farmers’ soil types and the linkage of the farmers’ soil types with the soil mapping units through geographic coordinates. The general framework of this study is outlined in Fig. 1.1.

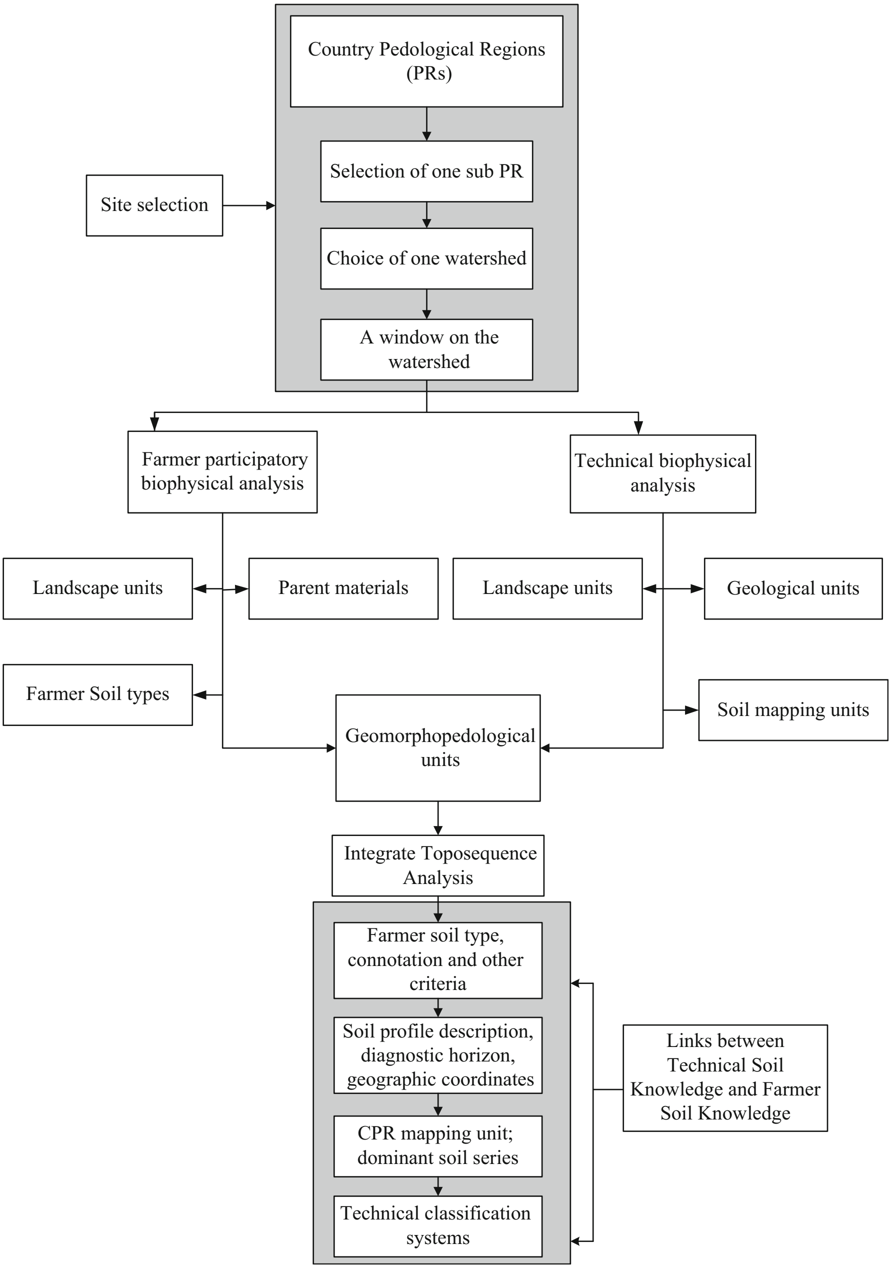

Fig. 1.1 General methodological framework

Site Selection Process

The multi-scale and nested hierarchy land system approach was used to select the study area (Wielemeker et al. 2001). Therefore, the sub-pedological region (SPR) of *‘Ferrasols on hills and Histosols in valleys’* was selected (Prioul and Sirven 1981). In this SPR, the *Akavuguto* watershed was chosen. For more detailed observations, the study area was considered by opening a window in *Akakavuguto* watershed (Fig. 1.2). At the site level, the soil-forming factors (Jenney 1941) and the soil–landscape relationship (Lagacherie et al. 1995; Wielemeker et al. 2001) were used to locate auguring points and soil pits.

Knowledge Integration Mechanism

First, the landscape context in which soils occur/soil–landscape relationship was used to identify the spatial distribution of soil in both the technical and the farmers’ knowledge systems (Gobin et al. 2000; Wielemeker et al. 2001). Secondly, the diagnostic horizon (let’s say argillic) of the farmers’ soil type (let’s say *Inombe*) was used to find its equivalent in the technical classification systems considering the CPR mapping unit where the profile was described. In this way, the diagnostic horizon, which is a technical concept, was used to link farmers’ soil names and their characteristics with the technical soil classification systems. Finally, using the Global Positioning Systems (GPS), geographic coordinates were recorded to link soil pits where profiles were located with the CPR soil mapping units.

Results

Within the CPR mapping units (1), Table 1.1 presents the relationship between Rwandan farmers’ soil types and most international classification systems used in Rwanda: *Soil Taxonomy* for CPR; the FAO 1990; the correlation system as used by MINAGRI (2002); and the INEAC classification system (Van Wambeke 1963) for pedological regions (Prioul and Sirven 1981). (2) Table 1.2 presents the relationship between farmers’ soil nomenclature and the pedogenetic legend (Birasa et al. 1990; MINAGRI 2002). The study has identified five landscape units in both the technical and the farmers’ soil knowledge. It also identified six main farmers’ soil types and recognized four diagnostic horizons which led to seven dominant soil series (Fig. 1.3; Tables 1.1 and 1.2).

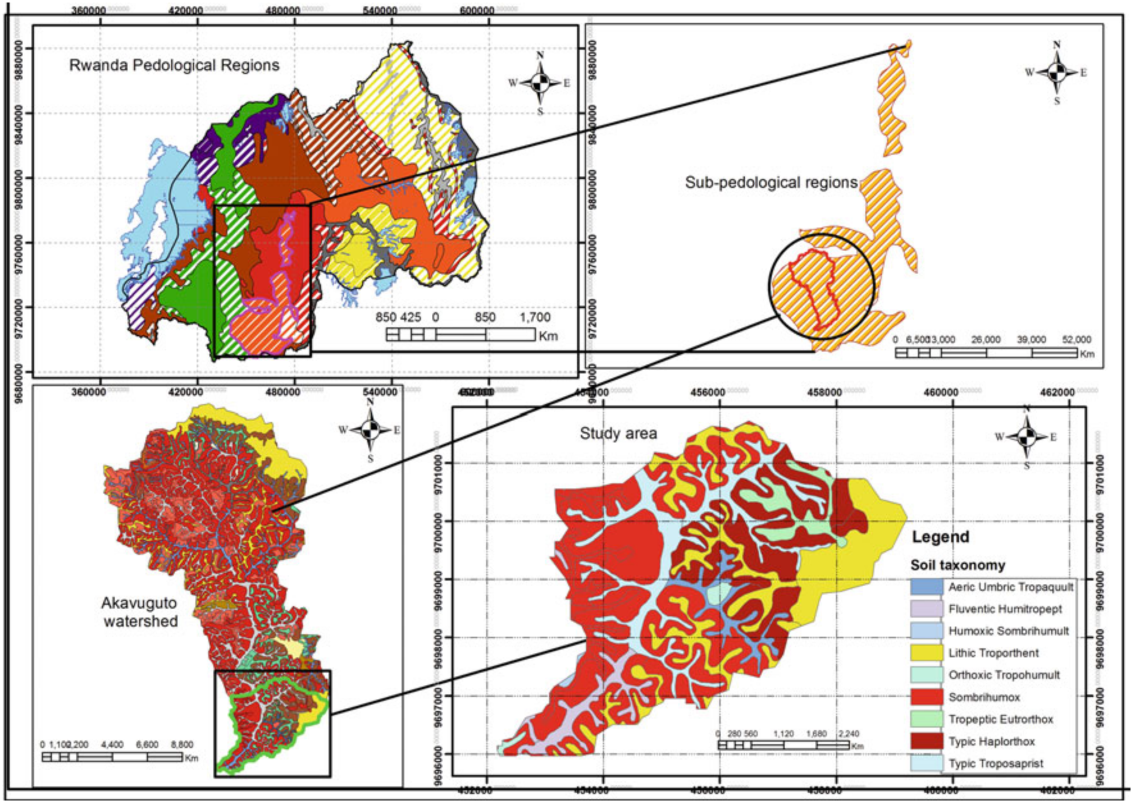

Fig. 1.2 Multi-scale and nested hierarchy site selection (1) *top right*: pedological regions of Rwanda 1:250,000 (Prioul and Sirven 1981) (2) *top left*: one sub-pedological region (3) *down left*: *Akavuguto* wateshed soil map 1:50,000 (Birasa et al. 1990) (4) *down right*: study site soil map

Table 1.1 Synoptic table linking farmers' soil names with technical classification systems within CPR mapping units

#	Land unit	Local name	Connotation	Diagnostic horizon	Geogr. coordinates	CPR mapping unit	CPR dominant soil series	Taxonomic legend (Family level) 1975	FAO 1990	UNEAC classification
1	Ibisi	*Urubuye*	Ibuye *means stone*. Urubuye *refers to a land unit dominated by shallow soils, stony – quartzite dominated – and sometimes with outcrops*	Entic Development	X = 467647 Y = 9698570	BUJ/GAT (MWO)	Bujumu (BUJ)	*Loamy-skeletal, mixed, non acid, isothermic Lithic Troportent*	*Distric Regosols/ Distric Leptosols*	*Entisols*
2	Imirambi	*Urusenyi*	Urusenyi *means gravel, and* Umusenyi *means sandy.* Urusenyi *refers to a shallow soil where gravel and sand dominate*	Entic Development	X = 453413 Y = 9698870	GAT/SAR (KIZ)	Gatonde (GAT)	*Loamy-skeletal, mixed, non acid , isothermic Lithic Troportent*	*Eutric Regosols/ Eutric Leptosols*	*Entisols*
3	Ibitwa	*Inombe*	Inombe *is derived from the verb* kunoomba *and it means puree. The connotation is stickiness.* Inombe *refers to a deep soil, stoniness, a red and sticky soil type when wet and hard with small cracks when dry*	Argilic	X = 455784 Y = 9701418	KNB	Kinombe (KNM)	*Clayey, kaolinitic, isothermic, Humoxic Sombrihumult*	*Humic ferralsols*	*Ferrisols à horizon sombre de profondeur*
4	Umucyamo	*Umuyugu*	Umuyugu *or I* Ikiyugu *is derived from the verb* kuyugumura. Umuyugu *soil type is a deep, non-sticky or stony soil. The connotative term in all* Umuyugu *soils is the friability, the poor resistance to working instruments. The* Umuyugu *soils are very porous, with very low bulk density and of a dusty aspect*	Oxic	X = 454530 Y = 9699456	MAT/KIA (FMB)	Mata (MAT)	*Clayey, kaolinitic isothermic Sombrihumox*	*Humic ferralsols/ Humic Acrisols*	*Ferralsols à horizon sombre de profondeur*
				Oxic	X = 456934 Y = 9699966	KIZ/NYG (KNB)	Kizi (KIZ)	*Clayey, kaolinitic, isothermic Typic Haplorthox*	*Haplic (rhodic) ferralsols*	*Ferralsols à humifères*

(continued)

Table 1.1 (continued)

#	Land unit	Local name	Connotation	Diagnostic horizon	Geogr. coordinates	CPR mapping unit	CPR dominant soil series	Taxonomic legend (Family level) 1975	FAO 1990	UNEAC classification
5	Utubanda	*Nyiramugengeri*	Nyiramugengeri *means peat bog. In its ethnopedological sense* Nyiramugengeri *refers to a soil type composed essentially of organic matter in a swampy area*	Histic	X = 455117 Y = 9699534	RL/RK(CR)	Rukeli (RL)	*Euic, Isohyperthermic Typic Troposaprists*	*Terric/Fibric Histosols*	*Histosols*
		Ibumba	Ibumba *derived from the verb* kubumba *that means to make ceramic vases. Ibumba means clay.* Ibumba *refers to a clayey alluvial and colluvial soil type, imperfectly drained in the valley bottom*	Argilic	X = 456057 Y = 9700527	RO/RK(RL)	Rwosto (RO)	*'Fine-silty, mixed, isothermic aeric Umbric Tropaquults*	*Distric (Humic) Cambisols*	*Hygrokaolisols*

Table 1.2 Links between the farmers' soil nomenclature and the CPR pedogenetic legend

	Landscape units	Slope (%)	Farmers' soil names	dominant soil series	Pedogenetic legend (Birasa et al. 1990)
1	Mountainous mass	>55	*Urubuye*	Bujumu (BUJ)	Soils derived from sedimentary or slightly metamorphic materials (schist, mica schist, and quartzite). Rock or saprolith before 50 cm. Entic Development. Yellow soils, well drained, clayey or clayey-loam, shallow soils presenting a minimal alteration, limited before 50 cm by the saprolith or parent material
2	Interfluve	0–4	*Urusenyi*	Gatonde (GAT)	Soil derived from acid magmatic rocks (granite and gneiss). Rock or saprolith before 50 cm. Entic Development. Yellow soils, well drained, sandy-clay-loam or sandy-loam, shallow and presenting a minimal alteration, limited before 50 cm by the saprolith or parent material
3	Plateau/shoulder	4–8 %	*Inombe*	Kinombe (KNM)	Soils derived from sedimentary or slightly metamorphic materials (schist, mica schist, quarzite) parent materials or saprolith with more than 100 cm. Advanced Argillic Development (A + Ap) and Spodic (S). Yellow or red soils, well drained, clayey or clay-loam, presenting an advanced and deep alteration (A + Ap), limited between 50 and 100 cm by a gravelly load (quartz, rock remains "*rubéfiés*" or transported, and/or laterite)
4	Hillside	8–12 %	*Umuyugu*	Mata (MAT)	Soils derived from sedimentary or slightly metamorphic materials (schist, mica schist, quarzite). Parent material or saprolith at more than 100 cm. Argillic-Intergrade-Oxic Development. Yellow or

(continued)

Table 1.2 (continued)

	Landscape units	Slope (%)	Farmers' soil names	dominant soil series	Pedogenetic legend (Birasa et al. 1990)
					red soils, well drained, clayey or sandy-clayey, presenting an advanced to ultimate and deep alteration; not limited before 100 cm by a gravelly load
				Kizi (KIZ)	Soils derived from basic rocks (gabbro, basalt, dolerite, amphibolites). Rock or saprolith at more than 100 cm. Argillic-Intergrade-Oxic Development. Red soils, well drained, clayey, developed in a mixture of materials derived from basic rocks and quartzite, presenting an advanced to ultimate and deep alteration, not limited before 100 cm by a gravelly load
5	Valley bottom	0–4	*Nyiramugengeri*	Rukeli (RL)	Soils derived from alluvial and colluvial materials and organic soils. Organic soils highly weathered (sapric), imperfectly drained, not limited before 100 cm by a gravelly load
			Ibumba	Rwosto (RO)	Soils derived from alluvial and colluvial materials. Mineral soils. Cambic Development. Soils imperfectly or moderately drained, clayey to clay-loam, not limited before 100 cm by a gravelly load

Discussion

As shown (Table 1.1), many soil classification systems have been in use in Rwanda and this has complicated communication and understanding of soil systems (Habarurema and Steiner 1997). On the one hand, this study contributes a framework to link the existing soil classification systems with the landscape where the soils occur. On the other hand, it allows linking the technical with the farmers' soil knowledge. By means of land units where soils occur, diagnostic horizons and geographic coordinates, the study contributes to fill the communication gap

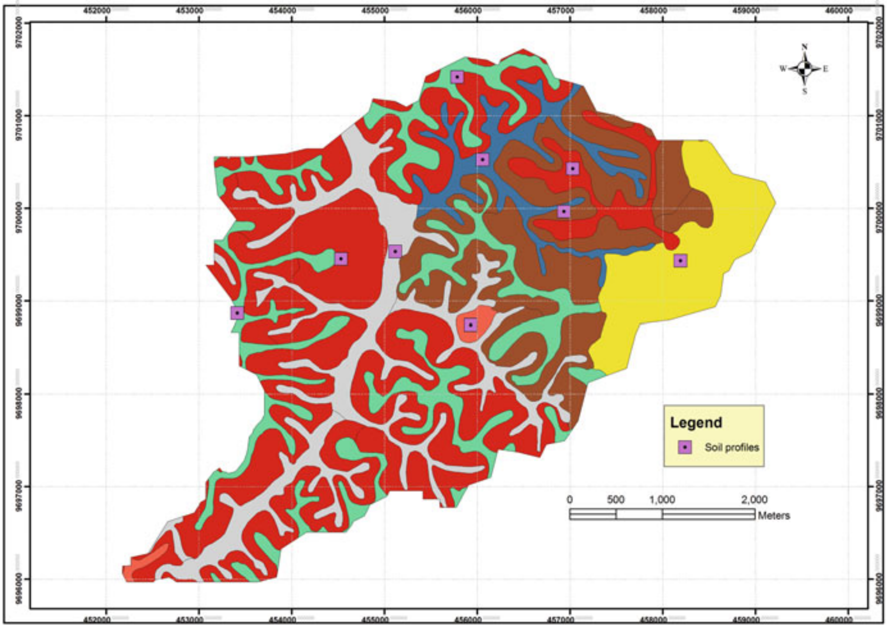

Fig. 1.3 Dominant soil series of the study area and the location of soil profiles: the legend of this map is elucidated in Tables 1.1 and 1.2

between technical and farmers' soil knowledge systems. The link between the two knowledge systems is a potential way of making the Participatory Integrated Watershed Management (PIWM) research model more effective. Indeed, the soil resource information being fundamental in agricultural research and extension, there cannot be effective and fruitful farmers' participation without interactive communication about soils. Effective farmers' participation requires communication bridges between the technical and farmers' knowledge systems.

In the study area, the land units where soils occur proved to be a very useful integration factor at watershed level (Tables 1.1 and 1.2). The strong equivalence between the farmers' names for land units and the technical geomorphologic units was reported (Rushemuka et al. 2009). A similar situation was identified by Barrera-Bassols et al. (2006) who observed a very high spatial correlation (99 %) between technical and farmers' relief units. This is especially true in hilly regions where the relief plays a major role in soil spatial distribution (Niemeijer and Mazzucato 2003). The identification of farmers' soil type diagnostic horizons – during the transect walks – proved to be another key integration factor at the site level. Geographic coordinates helped finally to link the profiles with the soil map units.

Two farmers' soil types were revealed as possibly having the same diagnostic horizon (Table 1.1). For instance, both the *Inombe* and *Ibumba* farmers' soil types have the Argillic diagnostic horizon. Likewise two different technical soil series may correspond to one farmers' soil type. For instance, both MAT and KIZ soil series correspond with the farmers' soil type *Umuyugu*. Since more than one technical soil series can be grouped into one single farmers' soil type, these soil types might also be related to suitability classes (Steiner 1998). This study has shown that despite what seems to be the fundamental impossibility of correlating technical and farmers' soil taxonomies due to the differences in the conceptual basis of the classifications (Habarurema and Steiner 1997; Niemeijer and Mazzucato 2003), both systems may be translatable through communication bridges for more complementarities.

Thus, on the one hand, the farmers' soil knowledge with its accurate, precise mental soil map, suitability classes and locally accessible vocabulary is not to be considered ideal. Indeed, in the extremely acidic and depleted soils such as the ones found in many areas of Rwanda, the farmers' technologies and traditional inputs are often no longer sufficient to cope with poor soils and the constraining socio-economic context. Thus, when it comes to introducing and adopting new technologies or new management practices, they have few reference points to guide their decisions (Cools et al. 2003). It is noted that farmers give less attention to the presence and influence of microelements and organisms smaller than 1 mm (Barrera-Bassols et al. 2006). They might have a knowledge gap regarding phenomena that they cannot see (Van Asten et al. 2009). Thus, they can often lack the in-depth scientific knowledge required to implement more complex practices such as using the nutrient value of manure (Ingram 2008), or any other newly introduced input such as fertilizers or lime. It is on such aspects that the farmers may need the scientific contribution.

On the other hand, the technical soil knowledge with its tacit side (soil surveyor mental model for instance) and currently hardly accessible language is not to be overlooked. On the contrary, it is very important for providing such insights as nutrients analysis, soil-specific fertilizer recommendations and adapted crop varieties and also environmental assessments. However, from an agronomic point of view, the expected outcome from technical soil knowledge is not so much the mapping of all local conditions – in terms of a detailed soil map – or the figures of soil properties – pH, CEC, Al, etc., – but the alternative way of doing things such as new extension recommendations – optimum fertilizer rates, a new suitable crop variety or a new sustainable land use. Therefore, a fruitful dialogue is much needed among farmers, pedologists, fertility experts and extensionists, by applying multi-defined soil functions linking crop performance with soil properties and by using classifications that provide useful and practical information (Barrera-Bassols et al. 2006). The challenge for scientists is now to guarantee these more direct benefits to the farmers that are absolutely necessary for sustaining a fair and stable relationship (Cools et al. 2003). This advice should be soil-specific but flexible and formulated in accessible language and researchers/extension workers should rely on farmers' soil nomenclature and location-specific knowledge for their application (Steiner 1998). Indeed, local soil classification is essentially fluid and flexible to cope with and account for the continuously changing soilscape and environmental context (Niemeijer and Mazzucato 2003). One way of achieving these soil-specific, flexible and accessible recommendations is to introduce them as part of the farmers’ frame of reference of soils – soil names and farmers’ perceptions. Using farmers’ terms for soil suitability classes improves communication and mutual understanding (Steiner 1998). Being aware of such perceptions can help to develop and promote technologies that are more relevant to the local context and concerns (Niemeijer and Mazzucato 2003).

Conclusion

The PIWM research model needs scientists from different disciplines, e.g., soil surveyors, soil fertility experts, breeders, agronomists, economists and extensionists, to communicate interactively with one another (scientific disciplines integration) and with the farmers (Knowledge systems integration) to develop soil-specific and transposable technologies at the watershed level. This requires a common language among different stakeholders for communicating soil resource information as the foundation of soil-related agricultural research and the scaling up of technology. Participation and integration involve interactive communication for innovation. The soil–landscape relationship, the diagnostic horizons of the farmers’ soil types and the geographic coordinates have proved to be effective communication bridges between the CPR and the farmers’ soil knowledge for practical purposes.

Therefore, scientists should fully exploit existing technical soil information (literature review) and identify farmers’ soil knowledge – (‘oral reviews’): both literature and ‘oral reviews’ combine to make the state of the art. From the state of the art and using farmers’ soil nomenclature for communication, both scientists and farmers will undertake sustainable land management schemes at the watershed level. The final step is to advance the farmers’ farm managerial capacity by incorporating scientific technology into their dynamic knowledge to sustainably increase production and improve their livelihoods. Thus, ‘grafting’ technical soil-related interventions on the farmers’ soil knowledge is indispensable to ensure the sustainability of such interventions and to facilitate the scaling up of technology. This process is facilitated because beneficiaries have been part of the technology development process. This is only possible if scientists are able to use the farmers’ soil nomenclature and perspectives while still being connected to technical soil knowledge through the communication bridges established between the two knowledge systems. We conclude that the technical soil knowledge linked to the farmers’ soil knowledge can wake up the CPR and make the PIWM more effective. However, we are not proposing a cut and paste strategy because the farmers’ soil names are not yet formalized and may vary or have different meanings according to the regions. Thus, for the moment, what is important is the methodological approach developed in this study which can be used in any watershed.

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Chapter 2
Intensification of Crop–Livestock Farming Systems in East Africa: A Comparison of Selected Sites in the Highlands of Ethiopia and Kenya

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B. Mesfin, and J. Gedion**

Abstract Mixed crop–livestock farms in the highlands of East Africa are undergoing a process of intensification but the constraints to intensification and the opportunities to overcome those constraints are not well understood. Survey activities were conducted from 2010 to 2011 in three sites in the highlands of Ethiopia and Kenya to (1) compare the extent of crop–livestock intensification, (2) assess constraints to intensification, and (3) explore options to overcome these constraints. Eight villages in each site were selected for the survey at two sites in Ethiopia (Kobo and Nekemte) and one (Kakamega) in western Kenya. The sites represented a gradient of productivity, increasing from the relatively extensive production system in Kobo to the more intensive production seen in Kakamega. Representative groups of 10–20 farmers were identified and interviewed in each village to gather quantitative group-level data at the village level. Results showed that the application of manure and the use of inorganic fertilizers and improved seeds were more pronounced in Kakamega and Nekemte than in Kobo. Unlike the two Ethiopian sites, 10 % of the households in the Kakamega site owned crossbred cattle. The level of

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intensification varied among the three sites mainly due to variations in market options and the availability of water and system-oriented technological options. Because of complexity and variation, different solutions are called for in different contexts. Dealing with some of the issues, for example, the water and technological options in Kobo, the market issue in Nekemte and the population-related issues and technological options in Kakamega, could lead to a more sustainable intensification of crop–livestock farming in the respective study sites.

Keywords Villages • Crop and livestock technologies • Trends on inputs and services use • Sustainability

Introduction

Small-scale crop–livestock farms represent a large fraction of the rural population in the East African highlands. However, the level and pace of intensification vary among regions, villages and farms. Variations in crop–livestock intensification relate to different rates of population increase, economic opportunities, cultural preferences, climatic events, lack of capital to purchase crop and livestock inputs and labour constraints.

Population increase has caused the fragmentation of agricultural land, and the conversion of land use from grazing and forest to agriculture in the East African countries. As a result, soil degradation through nutrient mining is becoming a major problem, though much of it is reversible with better integrated land management practices (Sanchez 2002).

Diversified income sources are the key to the generation of capital and subsequently contribute to the purchase of crop and livestock inputs, providing a potential route to more intensified production. The sources of income for the study site in Kenya were found to be more diversified than in the two Ethiopian sites (Duncan et al. (2012) Unpublished project sites report). Jayne et al. (2001) also reported a 50 % off-farm income generation for households in Kenya and a 12 % off-farm income share for Ethiopia. The increased diversity of income from different sources in the Kenyan site is due to the relatively developed and diversified economy, which enables farmers to use more crop and livestock inputs than in the Ethiopian sites.

The evolution of crop–livestock interactions in sub-Saharan Africa follows four major phases. These are the pre-intensification phase (crops and livestock are independent activities), the phase that corresponds to the emergence of crop–livestock interactions, the diversification phase and the specialization phase (Powell and Williams 1993). Studying the level of crop–livestock intensification in the East African sites helps the identification of where on this continuum farms currently lie, the assessment of gaps and opportunities, and the development of short to long-term interventions to move farmers towards more intensified production. The objectives of this study were to (1) compare the extent of crop–livestock intensification in terms of inputs utilization and access to markets and services, (2) assess the constraints to intensification, and (3) explore options to overcome these constraints in three sites in the highlands of Ethiopia and Kenya.

Methodology

Study sites: Three mixed crop–livestock farming system study sites were identified in two East African countries (Ethiopia and Kenya) to conduct studies on crop residues. Kobo and Nekemte sites represented the north eastern and western parts of Ethiopia whereas Kakamega represented the western parts of Kenya. The three sites were purposively selected to capture the maize and sorghum crop-based systems. Maize–beans are the dominant crops in Kakamega, maize-teff in Nekemte and sorghum–teff in Kobo. The sites represent a gradient of productivity with Kakamega being the most productive site and Kobo the least productive. Nekemte is a highland site with an altitude range of 1,748–2,418 masl. In terms of soil characteristics Vertisol is the dominant soil type in Kobo. This soil has more clay content; it cracks during the dry season and holds much water during the rainy season. On the other hand, the dominant soils in Nekemte and Kakamega are acidic; they fix phosphorus and make it unavailable to crops. A broad characterization of the three sites is shown (Table 2.1).

Village selection criteria were developed and applied in East Africa using images from Google Earth. Eight villages were selected in each of our three sites. The selection scheme was as follows: near-near: near to road, near to market; near-far: near to road, far from market; far-near: far from road, near to market; and far-far: far from road, far from market. For each category, two villages were selected by scrutinizing aerial images from Google Earth. A village survey instrument was prepared and tested in each regional site with research partners to ensure a thorough understanding of the questions. Village land area, cropping pattern, use of cropping technologies, types of crop residues, use of crop residues, trends in crop residue use, main constraints to crop production, number of adult animals in the village, composition of feed intake for ruminants and frequency of meeting of development agents with villagers are some of the guiding points included in the questionnaire. Representative social groups of 10–20 farmers were identified in each village and they responded as a group during the final village survey. A total of 24 villages were considered in the three sites (Table 2.2).

Table 2.1 Description of the three study sites in East Africa

	Kobo	Nekemte	Kakamega
Altitude (masl)	1,416–1,634	1,748–2,418	1,426–1,719
Major soil types	Vertisol	Nitisol	Oxisol
Mean annual rainfall (mm)	768	1,037	2,009
Mean annual temp (°C)	30	29	28
Total village population	330–2,250	196–391	400–5,000
Total village HHs	66–450	35–70	80–1,200
Total village land (ha)	77–910	74–164	200–900
Total cultivated land (ha)	66–280	61–149	160–810
Major crops	Sorghum, teff	Maize, teff	Maize, beans
TLU (tropical livestock unit)	141–1,004	69–213	121–673

Note: *masl* meter above sea level, *ha* hectare, *TLU* tropical livestock unit, *hhs* households, *mm* millimeter

Table 2.2 Study villages in East Africa (Ethiopia and Kenya)

No.	Nekemte	Kobo	Kakamega
1	Beko	Mesgid Genda	Mahiakalo
2	Gombo Boneya	Genfo	Muraka
3	Mandara Bake	Keyu Garia	Mukhonje
4	Kibi	Koba	Bukhatsi
5	Boneya	Hamusit	Ematere
6	Bata	Ayinama	Mabanga
7	Lugo	Hormat	Ataku
8	Gajo	Chorie	Bukondi

Results and Discussion

Farming Systems at the Three Sites

Cereal production accounted for a higher percentage of the allocated cultivated land in Kobo and Nekemte than in Kakamega (Table 2.3). Production of legumes in terms of the percentage of area coverage and number of households growing legumes was more pronounced in Kakamega than in Kobo and Nekemte. This has implications in soil fertility management and ecosystem sustainability.

The diversity of horticultural crops grown in Kakamega and the percentage of households involved in such farming were considerable. The number of households growing horticultural crops in Nekemte was also quite significant although the percentage of land allocated to them was small. The increased diversity of horticultural crops in Kakamega can be associated with proximity to input and output markets, access to credit, availability of germplasm and an adequate amount of rain (Sindi 2008).

Fallowing was practised in both Nekemte and Kakamega. Most households in western Kenya, including Kakamega, practised natural and improved fallows for short periods. The fallow system practice in Kakamega facilitates the restoration of soil nutrients that are depleted by intensive cropping. In western Kenya, about half of the farmers leave 10–25 % of their cropland fallow during the short-rains period (Amadalo et al. 2003). The need to exercise natural or improved fallow to improve soil fertility is not a priority in Kobo compared with Nekemte and Kakamega. The cultivated land in Kobo was concentrated in valley bottoms where soil transported by water erosion from the nearby mountains is deposited. The fallowing in Nekemte was longer and natural, i.e., without the deliberate inclusion of leguminous plants. It was also practised on agricultural lands where the soil was exhausted from continuous cultivation and soil acidification.

About 10 % of the households in Kakamega kept crossbred cattle whereas all the households in Kobo and Nekemte kept only indigenous cattle (Table 2.2). Although the demand for improved animal genetic resources such as crossbred cows had increased in the three sites, the response from the supply side was poor. Poor market conditions for animal products and increased prices of inputs also discouraged farmers from owning more crossbred cattle.

Table 2.3 Land area allocated to growing crops and the types of cattle kept by households at the three East African sites

Parameter	Kobo	Nekemte	Kakamega
Cropping system (Area ha)			
Cereals	963 (97)	581 (74)	1,238 (31)
Legumes	19 (2)	13 (2)	859 (22)
Oil crops	nd	54 (7)	nd
Horticultural crops	5 (1)	24 (3)	1,776 (44)
Fallow	nd	107 (14)	133 (3)
Households keeping cattle (%)			
Cross breeds	0.0	0.0	9.6
Indigenous breeds	100.0	100.0	90.4

NB: Nd refers to no data; Numbers in *parentheses* represent percentage of area coverage

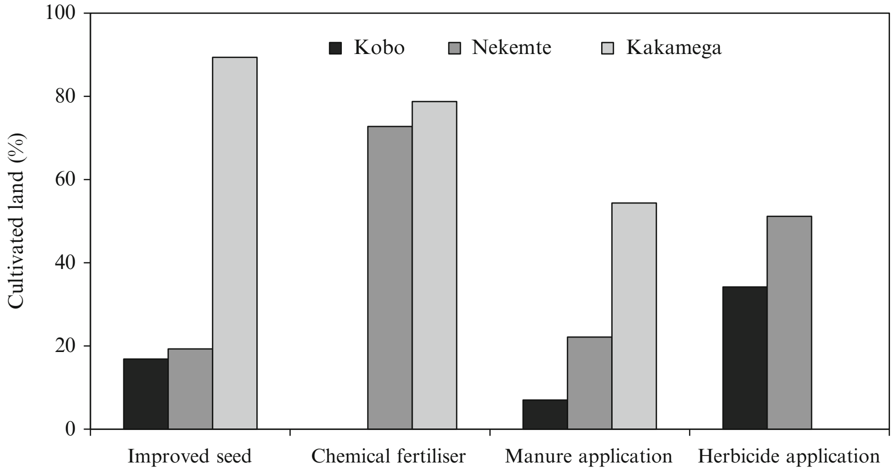

Fig. 2.1 Use of cropping technologies in the three sites in East Africa

Use of Cropping and Livestock Management Technologies at the Three Sites

The percentages of cultivated land that received chemical fertilizers in Nekemte and Kakamega were quite significant when compared to the Kobo site (Fig. 2.1). High rainfall, the nature of the soil type (P-fixing) and the production systems tended to compel the farmers to apply chemical fertilizers to sustain the productivity of crops in Nekemte and Kakamega. Most cultivated lands in Kakamega were planted with improved seeds. Weeds in Kobo and Nekemte were controlled by hand weeding and herbicide application. On the other hand, a large proportion of the cultivated lands in Kakamega depend on hand weeding for weed control. Manure application for managing soil fertility was very limited in the two Ethiopian sites as cow dung was one of the sources of energy for cooking food.

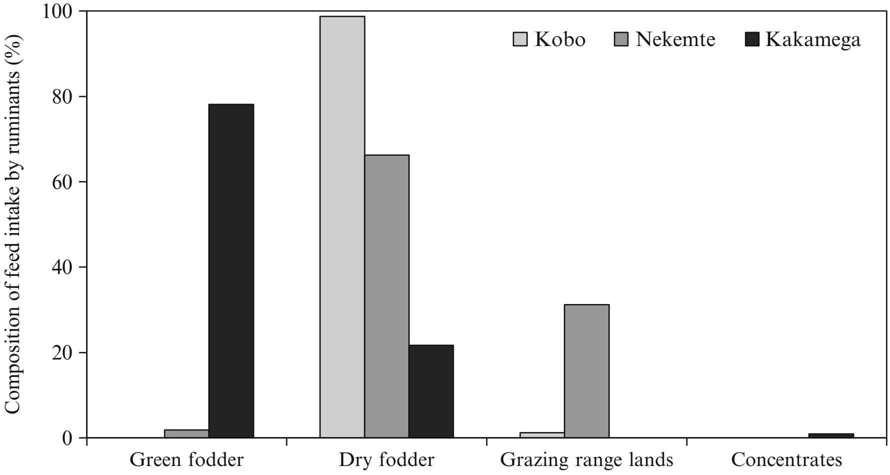

Fig. 2.2 Use of dry season livestock feed sources in the three sites in East Africa

Dry fodder (crop residues + stubble grazing) constituted 99 % of ruminant dry season feed intake in Kobo and green fodder (Napier grass + crop residues) constituted 78 % in Kakamega (Fig. 2.2). Residues from cereal crops and pulses combined with post-harvest stubble grazing accounted for over 90 % of all feed in the Ethiopian highlands (de Leeuw 1997). Growing and marketing of Napier grass was a common practice in most parts of western Kenya. The green fodder from Napier grass appeared to exist in the dry, rainy and harvest seasons. Napier grass was one source of cash income for the smallholder farming communities. It was commonly grown as strips and block plantings in the farmlands, on roadsides and in other niches. The contribution of concentrates (mainly composed of industrial by-products) to total livestock diet was found to be minimal across the three sites.

Constraints for Crop–Livestock Intensification

The intensification of crop production is constrained by weeds, diseases and pests high prices of inputs and low prices for outputs whereas livestock production is limited mainly by feed shortages, diseases and endo- and ecto-parasites (Figs. 2.3 and 2.4).

Rainfall distribution and intensity are highly variable in Kobo compared with Kakamega and Nekemte. The occurrence of drought is also very common in Kobo and the surrounding areas. Farmers plant different varieties of crops depending on the timing of the onset of rain. If the rain starts very early, they plant long-maturing varieties. Short-maturing varieties can be seen in most crop fields when there is a

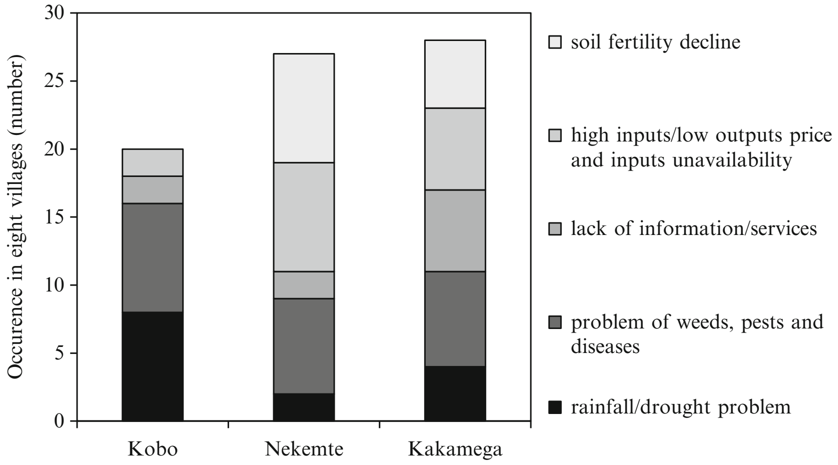

Fig. 2.3 Main constraints of crop production in the three sites in East Africa

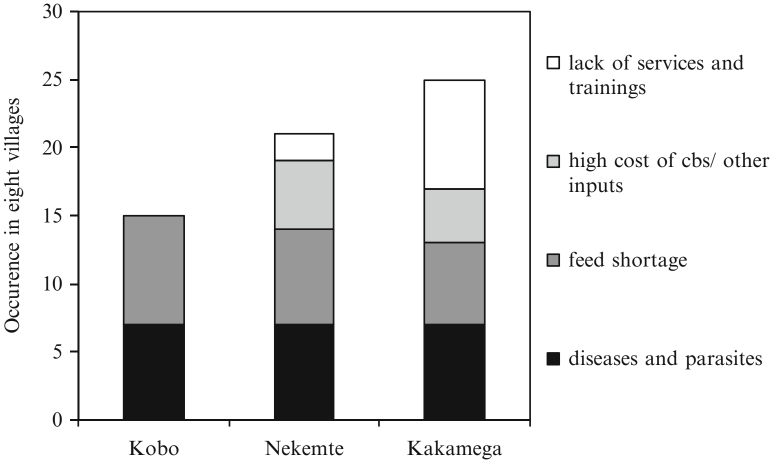

Fig. 2.4 Main constraints to livestock production in the three sites in East Africa

late onset and inadequate rainfall. Farmers also plant intermediate crop varieties during an average rainy season. The productivity of the varieties is different in terms of grain and crop residues. The long-maturing varieties, e.g., sorghum and teff, produce higher yields of grain and crop residues that can be used for various competing uses (Hailu Terefe 2011). The availability of alternative varieties also increases farmers' flexibility to respond to climate, market and social variations (di Falco et al. 2010).

Soil nutrient depletion has become a common feature in the East African countries although the degree varies from site to site. The problem is prevalent in Nekemte and Kakamega due to the acidic nature of the soil and other associated constraints. The dominant soils in Kakamega District, such as the Acrisols, Ferralsols and Alisols, are acidic. These three soil types constitute 79 % of the total area of the district (Mandere 2003). Plant nutrient deficiencies and toxicities of Al (aluminium), Mn (manganese) and hydrogen ion (H^+) exist in acid soils. Soil acidity is one of the factors contributing to the low yields of crops and crop residues (Sanchez et al. 1997).

Weeds, insects and pests affected the productivity of crops and crop by-products in all three sites. The most important weeds in Kobo were *Striga* spp. and *Parthenium hysterophorus*. *Striga* is a parasite mostly affecting sorghum, maize and teff. *Parthenium hysterophorus* colonizes arable lands, bare areas along roadsides and heavily grazed pasture. When animals graze the harmful *Parthenium* weed, milk becomes bitter. Estimates of crop losses from weed infestation in Ethiopia reach up to 40 % (Kebede Desta 2000). Stem/stalk borers were the most important insect pests of maize in Kakamega and Nekemte, and of sorghum in Kobo. In Kenya, stalk borers causes losses of 14 % of maize production nationwide (Groote et al. 2001).

High input prices (fertilizer, improved seeds) and low output prices (cash and staple crops and by-products) were common issues in Nekemte, Kakamega and Kobo although the level of the problem varied among the three sites. The problem is associated with the lack of infrastructure, such as road networks. The inadequacy of the road system, which is most important for market development in terms of the distribution of inputs and output to and from farms, is the most serious infrastructural constraint facing agricultural development. As a result of the poor road networks, smallholder farmers depend on inefficient forms of transportation including the use of animals. Underdeveloped rural roads and other key physical infrastructures have led to high transport costs for agricultural products to the market as well as for farm inputs, thus reducing the farmers' competitiveness.

Agricultural information and service delivery through extension was less efficient in Kakamega than in Kobo and Nekemte. The findings of the present study also showed that the villagers in Kakamega met extension experts once a month at the maximum and once a year at the minimum. On the other hand, 50 % of the villagers at Kobo (four villages) met development agents daily and the other 50 % (four villages) had access to extension service providers on a weekly basis. The frequency of meetings with extension experts in the last 10 years has also shown an increasing trend in the Kobo and Nekemte sites. The trend of access to extension experts in Kakamega showed no net change. The allocation of 3–4 development agents at Kebele level had improved the frequency of their meetings with farmers in the Kobo and Nekemte sites.

Shortages of animal feed and the incidence of diseases and parasites significantly affected livestock productivity in almost all the study sites. Animal feed beame scarce mainly during the dry season. As a result, animals died at an early age; they provided a low milk yield and draught power, and were marketed at a low price (Kindu 2001). The two major livestock diseases of economic significance in Africa in general are trypanosomiasis and tick-borne diseases (Latif 1992). Both affect subsistence and commercial farmers and limit the exploitation of productive land. Present methods of vector and disease control remain inadequate, costly and pose environmental problems (Latif 1992).

Potential Options to Overcome Constraints to Crop–Livestock Intensification

- Producing enough biomass: this can be achieved through the use of cropping technologies (water harvesting, irrigation, improved crop varieties) and intensive farming.
- Introducing compatible and high-value perennial crops; this would generate income for the poor farmers and improve the year-round soil cover.
- Implementing an integrated farming approach: this would help local communities to better address a number of issues at a time. It can also facilitate the search for alternative sources for various issues, e.g., alternative feed and fuel sources to save more crop residues for covering the soil and improving its fertility.
- Enhancing the knowledge of farmers: better management and the efficient use of land and water resources would boost crop and livestock productivity. This can be done through various capacity building schemes such as farmer-to-farmer informal visits, field visits, agricultural shows, demonstrations, farmers' exchange visits, advertisements, leaflets, posters and booklets, radio programmes, TV programmes, training, awareness-raising especially among policymakers and meetings/workshops (Owenya et al. 2001).
- Promoting participatory learning approaches: farmer field schools, for example, would strengthen farmers' understanding of the principles underlying intensive farming using various inputs and services.

Conclusion and Recommendations

The three study sites in East Africa had different levels of crop–livestock intensification because of variability in rainfall, in the adoption of crop and livestock technologies, and in access to input/output markets. Crop intensification was limited in all three sites with traditional low-input practices predominating. However, there was some evidence of the better use of improved seeds, chemical fertilizer and manure application for crop production in Kakamega. Green fodder was the dominant feed source in Kakamega while dry fodder (crop residues) dominated in Kobo. Nekemte was intermediate in terms of the importance of dry fodder resources. Concentrate feeding was minimal in all sites although very limited feeding of concentrates was evident in Kakamega. Dealing with some of the constraints that affect production could lead to a more sustainable intensification of crop–livestock farming in the East African highlands.

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Chapter 3

Rapid Assessment of Potato Productivity in Kigezi and Elgon Highlands in Uganda

G. Okoboi, I. Kashaija, R. Kakuhenzire, B. Lemaga, and D. Tibanyendera

Abstract A rapid assessment of potato production and productivity in Kigezi and Elgon highlands was conducted with the aim of understanding the extent of input use and the relationship between input use and productivity. Data from the Uganda Census of Agriculture 2008/09 and a Rapid Rural Appraisal survey were used in the analysis. The results revealed that Kigezi highlands led in potato production and productivity in Uganda. This could be attributed to the higher application/unit area of all inputs. Furthermore, the results indicated that, although the use of productivity-enhancing inputs, such as good quality seeds, fertilizer and fungicides, is fundamental to increasing potato yield in Uganda, the high prices of these inputs vis-à-vis the low prices for ware potato may render their application economically unviable. The results thus suggest the need to ascertain the economically optimal level of input use to minimize low or even negative marginal returns.

Keywords Potato • Productivity • Highlands • Uganda

Introduction

Potato (*Solanum tuberosum*) is an important crop in Uganda particularly in the highland areas where it is a staple food and a main source of income. The highlands in Uganda comprising Kigezi, Elgon and Rwenzori have more or less similar characteristics. That is, they lie at an altitude of 1,300–3,950 masl; the temperature

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ranges from 12 to 25° C; annual rainfall is bimodal and usually above 1,400 mm (NAADS 2004). Furthermore, these regions are generally densely populated, have young volcanic soils and land is fragmented into small plots (NAADS 2004). Kigezi highlands, found in south-western Uganda, comprises Kabale, Kisoro, Kanungu and Rukungiri districts; Elgon highlands in eastern Uganda include the districts of Mbale, Sironko, Manafwa, Bududa, Kapchorwa and Bukwo, according to the Uganda Bureau of Statistics report, June 2008 (UBoS 2008).

Because of the economic and food security importance of potato, the Government of Uganda and development agencies have implemented several interventions aimed at increasing the output and productivity of this crop. The national research system, for example, has released over 15 potato varieties since 1970 (Kaguongo et al. 2008). The NAADS programme, which is a government extension system, distributes seed potato and other recommended inputs, including fertilizers and fungicides, to farmers in districts where the crop is a priority enterprise under the NAADS programme. In addition, non-governmental agencies, such as the International Potato Center (CIP), African Highlands Initiative (AHI) and AFRICARE, have for over two decades supported potato production and post-harvest initiatives in Kigezi and Elgon highlands.

Notwithstanding the interventions, the potato yield in Uganda is still low, averaging 5 t/ha but with wide disparity in yields by region: Central 2.8 t/ha; Eastern 3.6 t/ha; Northern 2.2 t/ha and Western 5.2 t/ha compared with a potential yield of over 30 t/ha. The 5-year national development plan attributes low agricultural productivity to low and/or inadequate use of recommended production inputs (GoU 2010). For potato production, the key inputs recommended by the providers of extension services and/or provided by the NAADS programme to farmers include ‘quality’ seed potato, fungicides and fertilizer. There are no approved quality standards for seed potato production in Uganda or farms approved to produce such seeds. As a result, farmers rely on personal judgment or advice from agricultural extension staff when selecting the planting materials.

Although various initiatives, as highlighted above, have been undertaken in the country to promote the use of recommended inputs in potato production, little is known about the extent of use of these inputs. Furthermore, not much is known with regard to yield and profit arising from their use. Kelly (2006) argues that the use of improved technologies, particularly by smallholder farmers, depends on economic viability besides physical productivity. The objective of the study, therefore, was to examine the extent of use of recommended inputs including seed potato, fungicides and fertilizer in potato production; especially in the highlands of Uganda. Secondly, the study sought to provide insights into the relationship between the use of recommended inputs and productivity as measured by yield and profit.

Data and Methods

The study used two sets of data: secondary data from the Uganda Census of Agriculture (UCA) survey 2008/09 and from a primary survey. The data from the UCA survey, which covered the entire country, were collected by the Uganda

Bureau of Statistics (UBoS), the statutory national agency for data collection. The UCA survey was a sample census collected from 31,340 households. Of these, 2,297 households (7.3 %) were potato producers. In particular, 790 (34.4 %) of the sample households were from Kigezi and 82 (3.6 %) from Elgon. In terms of data collection by cropping season, 1,206 potato producing households were sampled in Season 2 (July–December) 2008 and 1,091 in Season 1 (January–June) 2009. The UBoS included weights (inflation factors) in the UCA survey to make the sample nationally representative.

The UCA survey had six modules, including those for Agricultural Household and Holding, Crop Area and Crop Production, (UBoS 2008). In the survey, data were quantitative on the area cultivated and qualitative on the use of inputs. The UCA data, however, did not include a section on the quantity and price of inputs as well as the price of outputs, which would be useful for economic analysis.

In view of the fact that data on the quantity and value of inputs used in potato production as well as outputs were missing in UCA 2008/09, a rapid rural appraisal (RRA) was conducted in Kigezi and Elgon highlands to collect these data quickly and cost-effectively from key informants including farmers, traders, processors, transporters, brokers, local government officials, researchers and extension agents. For the purpose of this paper, only data collected from farmers were utilized. The RRA research method integrates elements of formal surveys and unstructured methods of research, such as in-depth interviews or focus group studies (Crawford 1997).

A semi-structured questionnaire was designed and administered to 60 farmers: 30 from Kigezi and 30 from Elgon as one group of key informants in the potato value-chain. In Kigezi, data were collected from 15 farmers in Kabale district and 15 in Kisoro district. Similarly in Elgon, data were collected from 15 farmers in Mbale district and 15 in Kapchorwa district. At the district level, the selection of potato producers was purposive and guided jointly by the District Coordinator of NAADS and the Chairperson of the District Farmers' Fora who by virtue of their work are in close contact with farmers. Target respondents were from at least two sub-counties and included both subsistence farmers and market-oriented producers as classified in the NAADS programme.

As this was a semi-structured questionnaire, both quantitative and qualitative responses were solicited. Quantitative data among others included those on the quantity and price of inputs and outputs and marketing costs. Qualitative responses were solicited to provide further details with regard to quantitative data. Original survey data were standardized in metric units. For example, the area cultivated, which was reported in acres, was standardized to hectares; output, which was reported in bags, was converted into kilograms: one bag was assumed to weigh an average of 100 kg.

Descriptive and analytical methods, supported with qualitative narratives, were both used in the study. For example, the two-group mean-comparison test (Park 2009) was used to compare the extent of input use and the yield and profit outcome of potato producers in the study areas. Two-way fractional polynomial graphs were fitted to provide causal insights of the predicted relationship between the extent of fertilizer and/or fungicide use and the yield and/or profit. Fractional polynomials are alternative approaches to the traditional approaches for the analysis of continuous variables (Royston et al. 1999). Ordinary least squares (OLS) regression (Eq. 3.1) of yield/profit (y) on quantity of seeds (x_1), fertilizer (x_2), fungicides (x_3) and cost of labour and other inputs (x_4) was estimated to assess the statistical significance of the relationships. Where α and β in Eq. 3.1 are unknowns to be estimated and ε is the random term.

$$y = \alpha + \beta_1 \log x_1 + \beta_2 \log x_2 + \beta_3 \log x_3 + \beta_4 \log x_4 + \varepsilon \tag{3.1}$$

Results and Discussion

Table 3.1 shows the total area cultivated, output and yield of potato in Kigezi and Elgon highlands and the rest of the country. Results revealed that Kigezi produced almost half (47 %) of the national potato output on 40 % of total crop area in Uganda. Results furthermore indicated that potato yield in Kigezi was almost double that in Elgon.

Despite the fact that Elgon highlands lagged behind in production, on average, a higher proportion (59 %) of potato producers in this area use fertilizer compared with only 18 % in Kigezi (Fig. 3.1). Based on 2005 data, Kaguongo et al. (2008) reported that 40 % of potato producers in Elgon used fertilizer compared with 7 % in Kigezi. Interviews with farmers in Elgon revealed that this relatively high proportion was likely to be due to the long tradition of using fertilizer as a result of continuous information from the district authorities on land management. Communities living in Elgon face a severe land shortage, with fragmentation and degradation (Ingram and Reed 1998), which limits the expansion of the cultivated area. The availability of relatively cheap fertilizers imported/smuggled from Kenya, particularly in Kapchorwa district, was also cited by respondents as another possible factor. In contrast, the relatively low proportion of farmers using fertilizer in Kigezi was likely to be due to the scarcity and relatively high price of fertilizer as a result of the poor transport services in the area. Kaguongo et al. (2008) observe that the low use of fertilizers in Kigezi is rooted in the perception that land in the region was inherently fertile and there was no need to use external nutrient inputs.

Table 3.1 Area, output and yield of potato in major growing areas in Uganda

Region	Area (ha)	% of total area	Output (t)	% of total output	Yield (t/ha)
Kigezi highlands (n = 790)	10,832	40	72,617	47.0	6.7
Elgon highlands (n = 82)	972	4	3,616	2.3	3.7
Other areas (n = 1,425)	15,129	56	78,155	50.6	5.2
Uganda (n = 2,297)	26,933	100	154,388	100	5.8

Data source: UCA 2008/09

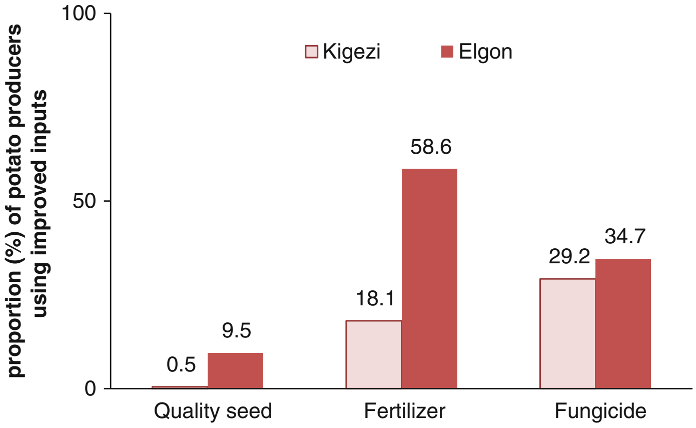

Fig. 3.1 Proportion of farmers using fertilizer and/or fungicide in potato production (*Data source*: UCA 2008/09)

In both Kigezi and Elgon, the RRA survey revealed that diammonium phosphate (DAP) and nitrogen-phosphorus-potassium (NPK) compound were the prevalent types of fertilizers used in potato production and applied mainly at the planting stage. A higher proportion (35 %) of farmers in Kigezi used fungicides than their counterparts in Elgon (29 %). Respondents reported the use of either Dithane M-45 or Ridomil Gold 68 WP. Rather more farmers use fungicides, particularly in Kigezi, and this may be due to the fact that, unlike fertilizer, fungicides were less bulky, available even in rural input shops, retailed in smaller quantities, such as 0.5 kg, and had a multipurpose use, including the control of diseases in other crops, such as tomato. Moreover, fungicides were highly recommended by extension workers for the control of a wide range of crop disease vectors.

The use of quality seed potato for ware production, in both Kigezi and Elgon highlands was generally low (Fig. 3.1). Most farmers reported using their own seeds retained from the previous harvest or those bought from a neighbour. The widespread use of local seeds, which are mostly likely to be diseased with bacterial wilt, may be another reason for the fairly high proportion of farmers using fungicides across the two regions.

The average level of input use and the corresponding yield and profit in potato production in the two study areas are presented in Table 3.2. Results indicate that mean area cultivated was 0.31 ha, seed use was 1.6 t/ha, fertilizer use was 173 kg/ha and fungicide use was 7.2 kg/ha. Resultant yields averaged 12.2 t/ha while profit averaged US$ 1152.91/ha. Potato producers in Kigezi used more seeds, fertilizer and fungicides/ha than their counterparts in Elgon. Corresponding yield and profit/ha were also significantly higher in Kigezi than in Elgon. All results except the area cultivated were statistically significant at less than 5 % level.

The use of relatively higher quantities/unit area of fertilizer and fungicides in Kigezi compared with Elgon may be due to the different recommendations provided by advisors in the extension services in the two regions, perhaps from a

Table 3.2 Extent of input use, yield and profit in potato production in Kigezi compared to that is Elgon (n = 60)

Input/output	Kigezi mean	Elgon mean	Overall mean	Difference mean
Area (ha)	0.34	0.28	0.31	0.06
Seed (t/ha)	1.72	1.41	1.57	0.32***
Fertilizer (kg/ha)	221.43	125.07	173.25	96.36***
Fungicide (kg/ha)	8.3	6.17	7.24	2.13**
Cost of hired labour and other inputs (US $/ha)	619.16	354.41	486.78	264.74**
Yield (t/ha)	14.25	10.26	12.26	3.99***
Profit (US $/ha)	1,311.76	1,014.56	1,163.16	297.19***

Data source: Field survey, February 2011
Note: ***, **, and * indicates statistical significance at 1 %, 5 %, and 10 % level

lack of knowledge on the economically optimal rate of input application. Kafeero and Namirembe (2003) observed that community extension agents as well as NAADS service providers do not have a uniform approach to extension services delivery. Also, most extension workers, let alone farmers in Uganda, lack basic and up-to-date knowledge about the state of soil nutrient balances so as to be able to provide appropriate fertilizer recommendations. Consequently, farmers who use fertilizer in crop production in Uganda more often guess than know the economically and/or technically optimal amount of input to apply.

Figure 3.2a shows the relationship between fertilizer use and yield; Fig. 3.2b shows the relationship between fertilizer use and profit. Figure 3.2c, d show the relationship between fungicide use and yield and profit keeping all other factors constant. In Fig. 3.2a–d, the slopes of the graphs of predicted yield and profit are somewhat upward, implying that a unit increase in the quantity of fertilizer or fungicide applied on potato had a positive, though not outstanding, effect on yield and profit.

Table 3.3 presents results of the OLS regression of Eq. 3.1: regression of yield and profit on physical factor inputs. Results indicate that a unit increase in the mean quantity of seeds and/or fungicides used had a positive effect on yield and profit but a unit increase in the mean quantity of fertilizer used had a negative effect. The coefficients of seeds and fertilizer in the profit regression were, however, the only variables that were statistically significant at 5 % and 10 % levels respectively. These results suggest that the mean quantity/ha of seed potato sown/ha by Ugandan potato producers may be below the optimum so that a unit increase in the quantity sown would boost productivity. According to International Year of the Potato (2008), about 2 t/ha of seed potato are sown compared to an average of 1.6 t/ha (Table 3.2) that are planted by farmers in Kigezi and Elgon, Uganda.

As for fertilizer application, results suggest a 1 % reduction in yield and a 3 % reduction in profit for a unit increase (1 kg) in the mean quantity of fertilizer applied. Though the predicted relationship between fertilizer application and yield was not statistically significant, it was rather surprising that it turned out to

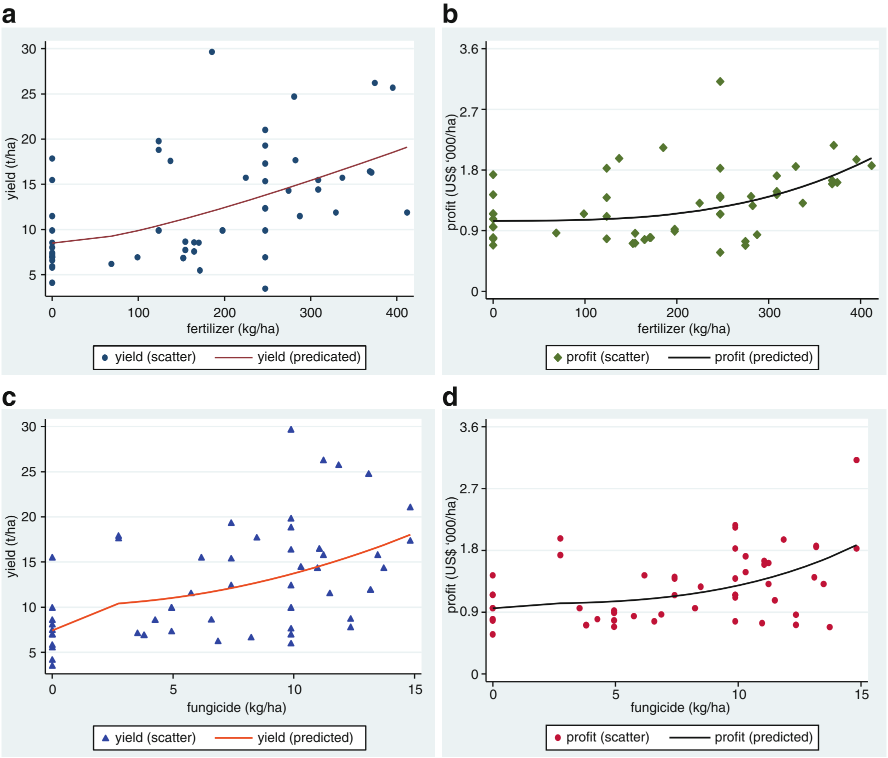

Fig. 3.2 (**a**) Predicted fertilizer–yield relationship. (**b**) Predicted fertilizer–profit relationship. (**c**) Predicted fungicide use–yield relationship. (**d**) Predicted fungicide use–profit relationship

Table 3.3 OLS regression: predicted effect of inputs use on yield and profit per acre

	Dependent variable = *ln*(yield)		Dependent variable = *ln*(profit)	
Explanatory variable	Coef.	t-value	Coef.	t-value
Ln (seed)	0.24	1.63	0.26**	2.2
Ln (fertilizer)	−0.01	−0.64	−0.03*	−1.7
Ln (fungicide)	0.06	1.02	0.01	0.61
Ln (hired labour and other inputs cost)	0.23***	8.02	0.14***	4.34
Intercept	0.76	0.71	−0.85	−0.96
Number of obs	60		60	
F(4, 55)	37.05***		8.0***	
R-squared	0.67		0.44	

Data source: field survey, February 2011

Note: ln implies natural logarithm of the variable. This transformation was applied to normalize variables as well as ease the interpretation of the coefficients. ***, **, and * indicates statistical significance at 1 %, 5 %, and 10 % level be negative– implying over-fertilization. In contrast, the fertilizer/profit relationship is not surprising, given the yield response and the relatively high retail price of fertilizer (about US$ 0.8/kg) which is about four times the farm-gate price (US$ 0.2/kg) of ware potato. The other factor that was found to have a significant effect on both yield and profit was the cost of hired labour and other inputs (such as transport and packaging materials).

Conclusions

Kigezi highlands lead in potato production and productivity partly due to a higher application/unit of the cultivated area of all inputs including seeds, fertilizer and fungicides. A higher proportion of farmers in Elgon highlands used fertilizer and fungicides but the rates of application/unit area were lower. Furthermore, results indicate that, while the use of productivity-enhancing inputs, such as good quality seeds, fertilizer and fungicides, is fundamental to increasing potato yield in Uganda, the high prices of these inputs vis-à-vis low prices for ware potato may render their application economically unviable. The results thus suggest a need to assist farmers to ascertain the economically optimal level of input use so as to minimize low or even negative marginal returns that may arise from an uninformed use of the inputs.

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Chapter 4

Farmers' Knowledge and Perception of Climbing Beans-Based Cropping Systems in Rwanda

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I. Nkurunziza, and A.R. Cyamweshi**

Abstract Because of the variability of agro-ecological and socio-economic conditions in the country, there is a need to understand climbing beans-based cropping system. This study aimed at assessing farmers' knowledge and perceptions on the productivity and profitability of existing systems based on climbing beans in Rwanda. Formal and informal surveys were conducted in five sites representing major agro-ecological zones producing climbing beans: Musasu in Central plateau, Nyamasheke in Impala, Musanze in volcanic land, Rwerere in Buberuka highland and Nyagatare in Eastern savanna. This study showed that existing cropping systems based on climbing beans are monocrops and intercrops with maize, cassava and banana. The monocrop is the dominant system reported by more than 55 % of the respondents in all target areas and is more productive than the intercropped systems. Farmers used *Calliandra*, *Pennisetum*, *Leucaena*, *Eucalyptus* and cassava plants as staking materials. Lack of stakes and of inputs including improved seeds, fertilizers, and pesticides as well as the incidence of pests/diseases were the major constraints in cropping systems with climbing beans. Agricultural policy should seek to improve the supply of all inputs to enable farmers to take full advantages of the improved systems.

Keywords Climbing beans • Cropping system • Socio-economic constraints • Agro-ecological zones

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Introduction

Common bean (*Phaseolus vulgaris* L.) has long been the major source of protein for the majority of Rwandans (Sperling and Munyaneza 1995). It provides a generous amount of energy (32 %) and micronutrients, such iron, zinc, proteins (22 %) and vitamins A and B that contribute to the development of the human body and cognitive growth (Miklas et al. 2006; Musoni 2008). *Phaseolus vulgaris* is also the most widely distributed *Phaseolus* species because it is grown in all the continents and across a broad range of environmental conditions (Baudoin et al. 2001; Broughton et al. 2003; Melotto et al. 2005). In Rwanda, for about two decades, the area devoted to climbing beans has increased from 20 to 53 % of the total area planted to beans, particularly in the Northern Province where it occupies 86 % and the Western Province where it occupies 69 % (Wortmann et al. 2004; NISR 2008).

The production of climbing beans in Rwanda is constrained by the scarcity of land, in addition to biotic and abiotic factors (Nzungize et al. 2011). However, the crop has desirable attributes that make it one of the priority agricultural commodities (Mugabo 2003) as the country needs to feed its rapidly increasing population. These attributes include a high yield potential which is 3–4 times more than other common bean types (Wortmann et al. 2004). It has tolerance to insect pests, diseases and drought; contributes to soil fertility improvement through atmospheric nitrogen fixation and provides cover during the growing season and potentially valuable residues for livestock feed. Therefore, systems based on climbing beans are compatible with the current Crop Intensification Program (CIP) for the food and nutrition of poor households in Rwanda.

Research on improved climbing beans in Rwanda can be traced to the early 1970s at the Institut des Sciences Agronomiques du Rwanda (Nyabyenda 1982; Rubaduka 1987) with a focus on variety options, cultivar spacing and staking options (Sperling and Munyaneza 1995). This process was done with a low involvement of farmers and as a consequence resulted in a low adoption of new technologies (Rahmeto 2007). Recently, it has become increasingly recognized that improving agricultural production systems including those with climbing beans is a complex process that requires the full participation of different stakeholders, including the farmers. Therefore, the sustainability of this process should be based on the farmers' knowledge and perceptions. The study aimed at identifying their knowledge and perceptions of climbing beans-based cropping systems in Rwanda. More particularly, it is focused on (1) existing climbing beans-based cropping systems (2) the socio-economic constraints of these production systems and (3) highly productive and profitable climbing beans-based cropping systems.

Materials and Methods

The Study Area

The survey was conducted in five districts: Burera and Musanze, both located in the Northern Province; Huye in the Southern; Nyamasheke in the Western and Nyagatare in the Eastern Province (Fig. 4.1). Table 4.1 presents a summary of the characteristics of the study districts including rainfall, mean temperature and related agro-ecological zones.

The size of the total population in the study area is estimated at about 10 million: 78 % of these (8 million people) are engaged in agricultural crop production (NISR 2008). The total arable land is about 1.4 million ha; which is 52 % of the total surface area of the country (REMA 2009).

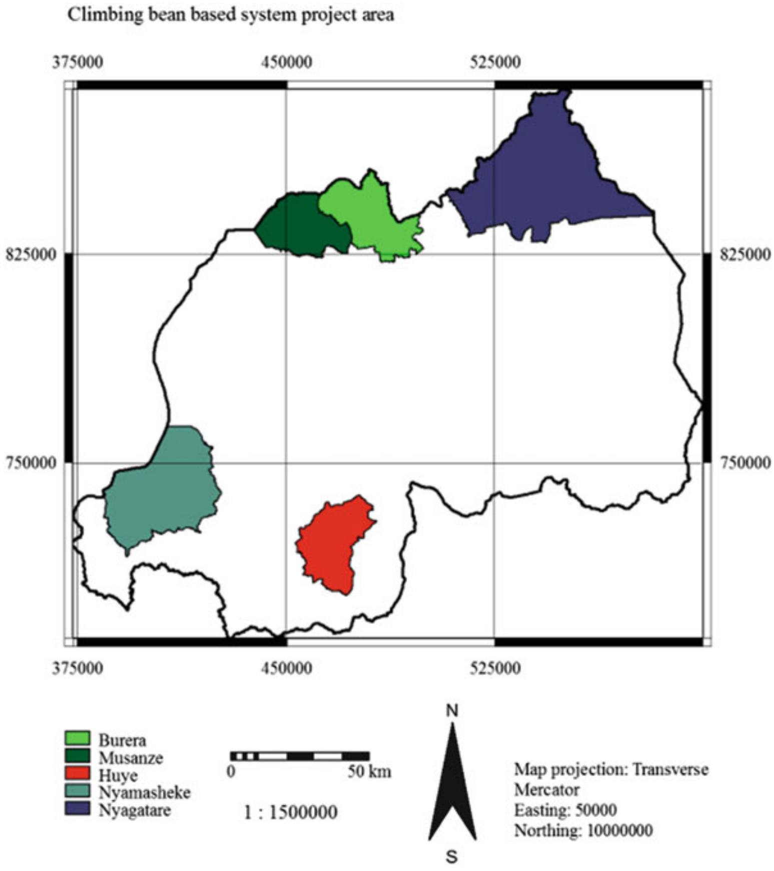

Fig. 4.1 Location of the study area

Table 4.1 Description of the study districts in Rwanda

Province	District	Rainfall (mm/year)	Mean temperature (°C)	Agro-ecological zone (AEZ)
Northern	Burera and Musanze	1,110–1,678	17	Volcanic land
Southern	Huye	1,025–1,993	19	Central Plateau
Western	Nyamasheke	1,203–2,360	16	Impala
Eastern	Nyagatare	891–1,255	20	Eastern savanna

Source: Verdoodt and Van Ranst (2003)

Sampling Techniques and Data Collection

The choice of districts was intended to represent the four provinces of Rwanda. A multi-stage sampling technique was used. One district with highly intensive cultivation of climbing beans was purposively selected in each province, except in Northern Province where two districts were selected because of the dominance of the crop there. In each district, one sector and one cell were purposively selected. In each cell, a sampling frame was drawn, based on a list of farmers. The sampling frame within each cell was stratified by gender. Equal numbers of farmers were selected in all cells. Thus, 450 farmers were selected to participate in the interviews.

Data were collected using the techniques of a formal survey and participatory rural appraisal (PRA). Interviews were conducted with farmers using a structured questionnaire to obtain information on their knowledge and perceptions of climbing beans-based cropping systems, the related constraints, advantages and opportunities. The PRA was carried out in five sites which represented the major areas growing climbing beans in Rwanda; these were Musasu, located in the Southern Province; Nyamasheke in Western Province; Musanze and Rwerere, both in Northern Province, and Nyagatare in Eastern Province. A check list was pre-designed to guide the discussion. Between 15 and 20 key informant farmers were selected in each site as participants in discussion sessions based on some socio-economic characteristics, notably, gender, age, and wealth category.

The survey was conducted by a multidisciplinary team, including socio-economists, experts in soil and water management, and crop and livestock scientists. During discussions, farmers were split into four groups where each group was composed of 5–10 people with different socio-economic characteristics such as sex, age, education, etc. The first group focused on the socio-economic aspects of the area; the second looked at components of soil and water management; the third focused on the climbing beans-based cropping systems of the area and the fourth focused on handcraft and services. Findings from discussions in each group were presented in plenary sessions for further improvement.

Results

Socio-economic Characteristics of Respondents

Results in Table 4.2 show that between 56 and 87 % of households were male-headed while female-headed households were between 13 and 44 %. A large proportion of household heads were in the age range of 46–60 years. More than 58 % were married and more than 55 % of them had completed primary education. Agriculture was the principal economic activity. The average land size for the households varied between 0.67 and 0.93 ha.

Table 4.2 Socio-economic and demographic characteristics of the study areas

	Province			
Characteristics	East	North	South	West
Gender of household head (%)				
Male	77.6	68.9	55.9	86.7
Female	22.4	31.1	44.1	13.3
Age group (years) (%)				
<30	23.1	18.1	11.2	11.0
31–45	24.9	34.7	17.3	49.9
46–60	36.8	34.3	44.5	36.0
61–75	13.6	11.8	21.6	3.1
>75	1.6	1.1	5.4	0.0
Marital status (%)				
Single	4.7	5.2	0.0	3.1
Married	84.6	75.0	58.1	84.8
Widowed	9.3	19.2	40.4	9.1
Divorced	1.3	0.5	1.5	3.0
Education level (%)				
Illiterate	3.8	26.7	33.2	16.0
Vocational training/adult literate	4.6	7.6	3.8	3.0
Primary	55.5	57.2	55.2	70.8
Secondary	1.6	7.9	7.3	8.7
Tertiary	0.0	0.6	0.0	1.5
Occupation (%)				
Agriculture	64.6	53.4	63.1	51
Animal rearing/livestock keeping	23.2	22.5	21.3	23
Crop and animal farming	7.3	11.6	9.0	9.0
Handicraft	1.2	4.8	1.6	5.0
Bee keeping	0.0	0.0	0.8	0.0
Fishing	0.0	0.0	0.0	2.0
Trading	1.2	3.2	0.8	1.0
Farm waged labour	0.0	2.4	1.6	1.0
Civil servant	2.4	2.0	0.8	6.0
Average land holding (ha)	0.93	0.67	0.80	0.86

Table 4.3 Climbing beans production systems across the study areas

	Province (%)			
	East	North	South	West
Cropping system				
Pure stand	61.5	85.9	71.8	85.2
Intercropping	30.2	12.4	20.2	11.7
Mixed cropping	8.3	0.9	5.8	1.3
Use of improved climbing beans varieties				
Yes	56.9	52.7	69.5	73.3
No	43.1	47.3	30.5	26.7
Source of improved varieties				
Specialized shop	0.6	7.2	0.0	6.2
Market	43.3	36.1	22.3	31.3
Owned	39.3	41.3	49.0	29.9
NGO	0.6	1.3	0.0	4.7
NARS	6.2	7.4	17.8	2.8
Extension services	0.6	2.7	1.6	3.8
CBO	0.6	1.8	4.0	10.0
Traders	0.6	0.4	0.8	4.7
Friend/relative	7.9	1.6	4.0	5.7
Other farmers	0.6	0.4	0.4	0.9

Climbing Beans Production Systems

The study identified three cropping systems with climbing beans across the study area: pure stand, intercropping and mixed cropping (Table 4.3). The pure stand system was the dominant cropping system reported by more than 61 % of the respondents. The climbing beans intercropping system was reported by from 12 to 30 % of the respondents. More than 52 % of farmers growing climbing beans used improved varieties obtained from own-saved seeds from previous harvests or purchased from local markets.

Constraints in Climbing Beans Production

The major constraint to production was a lack of stakes as reported by more than 21 % of farmers in the study area. Other constraints included the unavailability and high cost of fertilizers, drought, pests and diseases and a lack of knowledge (Table 4.4).

Fertilizer Use and Soil and Water Conservation

The major fertilizers used were farmyard manure (64–79 % of farmers), followed by inorganic fertilizers (20–36 % of farmers); compost was the input least used in all regions (Table 4.5).

Table 4.4 Constraints to climbing beans production across the study area

	Province (%)			
Constraints	East	North	South	West
Lack of stakes	30.0	25.1	21.7	21.4
Lack of fertilizers	14.7	11.8	16.3	17.3
High cost of fertilizer	4.7	7.3	9.5	7.3
Rodents	8.4	8.8	8.6	15.9
Drought	15.8	9.9	20.8	3.2
Shortage of manpower	2.1	1.3	1.8	0.9
Shortage of land	1.6	1.9	3.2	4.1
Pest and diseases	8.4	7.5	6.8	12.7
Low seed quality	1.1	4.1	3.6	0.0
Lack of knowledge	1.6	3.9	2.7	6.4
Unprofitability of the crop	2.1	0.2	0.9	0.0
Late cultivation	1.6	1.9	0.9	0.5
Lack of cords for staking	0.0	0.4	0.9	0.5
High transportation cost of stakes	0.0	0.4	0.5	1.4
Lack of seeds	6.3	4.9	1.8	4.5
A lot of rain	1.6	10.5	0.0	4.1

Table 4.5 Fertilizer use and farmers' practices to conserve soil and water

Districts	Type of fertilizer	Proportion of farmers using the technology (%)
South	Farmyard manure	78.9
	Compost	1.4
	Inorganic fertilizers	19.7
West	Farmyard manure	63.8
	Compost	0.1
	Inorganic fertilizers	36.1
North	Farmyard manure	79.0
	Compost	0.0
	Inorganic fertilizers	21.0
East	Farmyard manure	63.8
	Compost	0.0
	Inorganic fertilizers	36.1

Discussion

The high percentage of households headed by males can be explained by Rwandan cultural patterns. These results reflect the traditional norms where the male members take the lead in decision-making. However, regarding climbing beans production, it has been found that women are more involved than men (more than 27 %). The results confirm the greater role of women in the production of household food security crops (NISR 2008). This is also in accordance with Sperling and Berkowitz (1994) who reported that households headed by women are as likely as male-headed households to plant climbers. As a consequence, the production of climbing beans is likely to be reduced if women are denied access to relevant resources (knowledge and inputs).

The majority of household heads are within the active age and are married. This is consistent with results from other studies that showed that Rwandan population consists of a young (NISR 2008) and dynamic labour force. The large percentage of educated household heads reflects their capacity and skills for actively participating in the process of generating technologies for early adoption. In accordance with results from the 2008 national agricultural survey in Rwanda, this study revealed that farmers form a large percentage (>55 %) of household heads (NISR 2008).

The average land size (less than 1 ha) confirms results from other studies that per capita land size in Rwanda is 0.7 ha (MINAGRI 2009) and can be explained by the high annual demographic pressure of 3 % (Thaxton 2009). This situation requires intensification measures to sustain crop production systems. Climbing beans have shown a high potential of about twice the yield of local bush bean on a small area as the crop allows the exploitation of the aerial surface (Sperling and Berkowitz 1994; Sperling and Munyaneza 1995).

The existing production systems for climbing beans in Rwanda are pure stand, intercropping and mixed cropping. Similar results were reported by previous studies (Wortmann et al. 1998). The pure stand and intercropped systems are dominant across agro-ecological zones which could suggest cropping specialization leading to high harvest indices and profitability (Gebeyehu et al. 2006).

In the pure stand system, farmers use different types of stakes including mainly wood from agroforestry species such as *Grevillea*, *Leucaena*, *Calliandra* and Bamboo. This implies the adoption of introduced agroforestry species which reversed the traditional practice where farmers were relying on hedges or dead wood as the source of stakes (Sperling and Berkowitz 1994). The agroforestry species are preferred by farmers to other types because of their long durability and because they can be used several times and in several seasons. The majority of farmers (79–95 %) perceived the pure stand to be high yielding, resistant to crop diseases, early maturing and labour saving. It is most likely to be dominant in the North and West since these areas are favoured by climate conditions, soil fertility and the relative abundance of forests as a source of stakes. Furthermore, these two regions are known to be the traditional areas of climbing beans production (Sperling and Munyaneza 1995) and that can explain the predominance of this system.

In intercropping, climbing beans were grown in association with maize, banana, coffee and cassava where these crops were used as staking materials. The advantages of this system were reported by farmers (45–78 %) to be high yields, risk reduction, maximization of land use and income diversification. The relative prevalence of this system in the East and South regions can be explained by the intensification of the maize crop especially in the East where it serves as stakes when intercropped with climbing beans. In these areas, the shortage of stakes because of limited forests can justify the use of this system.

The results from this study have shown that the majority of farmers used improved varieties of climbing beans. Different factors account for this including the promotion of high yielding varieties by extension services, research institutions and various development organizations. Earlier studies have shown a large percentage of farmers (>55 %) adopting improved cultivars (Sperling and Munyaneza 1995). Farmers acquire seeds mostly from local markets where seed multipliers are considered the main suppliers.

Farmyard manure is mainly used by the majority of farmers as it is considered to be the best fertilizer (Hagergon et al. 1997). In accordance with findings of Berding (1991), this practice is very common in the North, South and West. However, in the East where livestock are concentrated, the practice of an extensive system limits the availability of farmyard manure (Zaongo et al. 2002) and hence explains its relatively low use in this region. Farmers perceive that this practice contributes to water conservation by trapping water between lines. Lack of adequate knowledge and sources of material for compost making can account for its low utilization by farmers across all the regions.

The major constraints in the production of climbing beans are lack of stakes, drought, lack of fertilizers, incidence of pests and diseases, rodents and insufficient availability of improved varieties. This confirms the findings of Gebeyehu et al. (2006) and Nzungize et al. (2011). The shortage of forests and high cost of producing agroforestry species explain the severe lack of stakes observed in the East compared with other regions. The limiting factors to fertilizer use were related to the low skills/knowledge of farmers on how to apply them; high costs and low availability at the farm level. These results are in accordance with those reported by Kelly et al. (2001) cited in Mugabo (2003). These constraints could reduce the likelihood of adopting improved production systems being adopted and productivity thereby increased.

Results from this study provide information on climbing beans-based cropping systems in different agro-ecological zones of Rwanda that can serve as a basis for agricultural interventions in rural areas but also for developing and fine-tuning research at the national and regional level in similar conditions.

Conclusion and Policy Implications

Climbing beans are an important crop that plays a significant role in improving household nutrition, food security and income for small-scale farmers in Rwanda because the crop is grown across diverse agro-climatic zones of the country and under different production systems. This study determined the relative importance of mono- and intercropping as land use systems. It confirmed farmers' preference for mono-cropping using improved varieties due to the perceived yield advantage, resistance to crop diseases, early maturity and labour-saving strategy associated with pure stands. The farmers preferred woody stakes because of their durability for reuse several times across cropping seasons to reduce costs. Nevertheless, drought, inadequate options for soil fertility management and pests and diseases remain socio-economically potent constraints to the adoption of the crop. Therefore, policy and other institutional interventions that improve input distribution are required to increase farmers' access to inputs. These include the support of cooperatives and farmers' associations for an increased access to agricultural credit. Based on the above findings, further studies should be undertaken to assess the productivity and financial profitability of cropping systems with climbing beans. The high costs of woody stakes justify studies on the socio-economic viability of alternative staking methods.

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Chapter 5

Securing Crop Phosphorus Availability in the Humid Tropics: Alternative Sources and Improved Management Options – A Review

Alhaji S. Jeng

Abstract In many low input agricultural systems of sub-Saharan Africa (SSA), phosphorus (P) is one of the mineral nutrients most limiting for plant production. The most important reasons for this are: (1) the generally low P content of the highly weathered tropical soils, (2) the relative unavailability of inherent soil P for plant uptake, (3) the relative speed at which applied soluble sources, such as inorganic P fertilizers and manure, become fixed or transformed into unavailable forms, and lastly (4) the poor management of on-farm organic resources. Biotechnological methods and cultural practices should be used to facilitate the availability of native and applied P. An extensive review of the literature has revealed that P-solubilizing micro-organisms in soil and P-enhancing plant species are both very effective in the management of scarce phosphorus resources in the soil. The recycling of crop residues, integration of green manures and crop rotations, application of animal manures, domestic and industrial wastes are all important ingredients of the integrated management of P. In sub-Saharan African agriculture, much of the emphasis should be placed on integrated soil fertility management (ISFM), which is a set of practices that necessarily include the use of mineral fertilizer, organic inputs and improved germplasm, combined with the knowledge on how to adapt these practices to local conditions for increased production efficiency. Increased and sustained agricultural production and productivity in SSA must make use of all sustainable means of production, in an integrative manner. In striving to achieve food security, the continent must not be torn between conventional and organic farming practices, but must focus on ISFM approaches which explore synergies that reduce leakages and recover and reuse nutrients, especially P.

Keywords Phosphorus resources • Availability • P solubilization • Plant breeding • Biological techniques • Crop varieties • ISFM

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Introduction

Africa, especially sub-Saharan Africa (SSA), has the world's lowest per capita agricultural production causing widespread chronic food insecurity and poverty. Statistics indicate that over 200 million people are undernourished or hungry (Kidane et al. 2006; The Worldwatch Institute 2011). The situation is aggravated by the high population growth rate (3 %) relative to the continually reducing cereal (food) production and per capita area of arable land which declined from 0.55 ha in 1961 to 0.23 ha in 2009 (FAOSTAT 2012). We have, in other words, a serious fall in per capita food production (Fig. 5.1), a situation that started in the mid-1970s.

The dominant constraint to increased agricultural and food production in SSA is the low nutrient status of the soils. Negligible quantities of phosphorus (P) and nitrogen (N) and low organic matter contents have combined with the lack of bases to make low soil fertility the major biophysical constraint affecting agriculture, generally, and causing declining per capita food production (Sanchez et al. 1997). Food production cannot be increased because of nutrient-poor (infertile) soils. Moreover, the rate at which nutrients are being extracted from the soil has also accelerated dramatically and replacement rates are often being exceeded by extraction rates (Smaling et al. 1996, 1997).

Of the essential macronutrients, P is the most limiting nutrient for acceptable yields of many crops in African agriculture (Kogbe and Adediran 2003). While N inputs can be naturally available through biological N fixation (Bohlool et al. 1992), P has to be applied, mainly as mineral fertilizer. However, like that of N, the soil's P status can also be improved by manipulation of the biological system of the soils (Srivastava 2010). In highly weathered, acid tropical soils, P fixation by sesquioxides of Al and Fe (hydro)oxides is a serious constraint to its availability

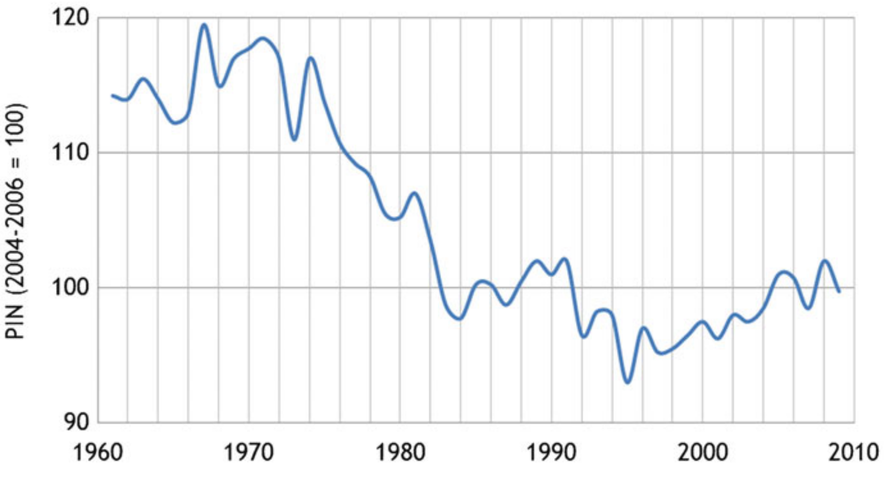

Fig. 5.1 Gross per capita food Production Index Number (PIN) for Africa South of the Sahara. (2004–2006 = 100) (*Source*: FAOSTAT 2012)

to crops (Craswell and Pushparajah 1989). Large amounts of phosphate fertilizers are needed to overcome this high P-fixation capacity (FAO 2004), correct the soil P deficiency, obtain reasonable yields and produce adequate food and fibre (Sanchez and Buol 1975; Date et al. 1995). Large amounts of inorganic fertilizer are however unaffordable to the African subsistence farmer. Reversing the trends of food insecurity and poverty must therefore make use of integrated practices and technologies for sustainable agricultural production. The aim of this paper is to highlight the importance of P as a plant nutrient and its place in African agriculture, and to emphasize the need to develop and adopt novel technologies for its enhanced acquisition/conservation and better management of the available sources (organic and inorganic).

Importance as a Plant Nutrient

Phosphorus is essential to all living organisms. It is irreplaceable in those compounds on which life processes depend. It is an important component of enzymes which are the key players in energy transfer processes which drive growth processes in all living things. In the human body, 85 % of the approximately 800 g of P are found in bones and teeth, mainly as the hydroxyapatite form (Tomassi 1992). The remainder is distributed in skeletal muscle, liver, gut, skin, nervous tissue and other organs and tissues, mainly in the form of organic esters. In plants, P is important in the growth process, photosynthesis, which converts CO_2 to sugars. It is also an essential component of nucleic acids in which complex Deoxyribonucleic acid (DNA) and Ribonucleic acid (RNA) structures carry and translate the genetic information which controls all living processes, such as the production of proteins and vitamins.

It is clear from the above that plants that do not receive optimal amounts of the element will have their growth severely retarded. Deficiency, not only affects plant growth and development (vegetative), but also the generative/reproductive aspect of plant growth, decreasing the formation of fruit and seeds and delaying ripening.

The World's Phosphate Reserves

Phosphate fertilizers are derived mainly from phosphate rock (Cordell et al. 2009), although organic fertilizers, such as composts, crop residues and slaughter house wastes, are also important. Jeng et al. (2004, 2006) have demonstrated the importance of meat and bone meal as a source of P. The importance of this element and its relative scarcity in the environment is probably the reason for the frequent studies assessing the global amounts that may still be available to man as mineral material. Terminologies such as phosphate rock "reserve" and "reserve base" have been coined in this effort.

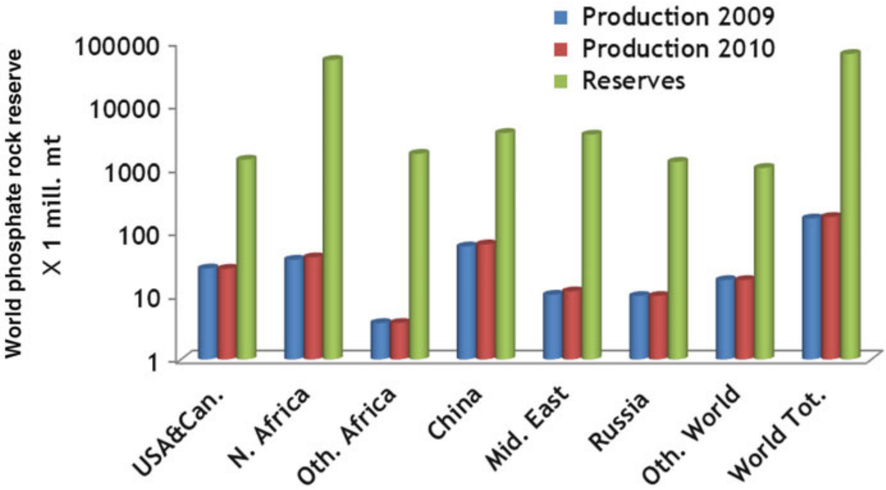

Fig. 5.2 World phosphate rock reserve estimates based on IFDC study (*Source*: USGS 2011)

The phosphate rock "reserve base" is the in-place, demonstrated economically exploitable rock phosphate resource (Schröder et al. 2010), while the "reserve" is defined as the part of the reserve base which could be profitably mined under prevailing costs, market prices and technology. Several studies suggest that phosphate rock reserves are limited and could be depleted within 100 years (Cooper et al. 2011).

Recently, the US Geological Survey estimated that world's phosphate rock reserves amounted to about 65 billion tons (USGS 2011) (Fig. 5.2). Over 65 % of these reserves are concentrated in Morocco, the remainder is found in the USA, Jordan, China, South Africa and Senegal. Being in the control of only a handful of countries, phosphate rock reserves can be subject to international political influence. Morocco has a near monopoly on the Western Sahara's reserves, China is drastically reducing exports to secure the domestic supply, US has less than 30 years' of supply left while Western Europe and India are totally dependent on imports (Rosmarin 2004; Jasinski 2006). For SSA, there has been no significant change in phosphate and potash imports during the past decade (Gregory and Bumb 2006).

Earlier estimates indicated that the inexpensive rock phosphate reserves could be depleted in as little as 60–80 years (CAST 1988; Runge-Metzger 1995). Recent estimates (IFDC 2010; USGS 2011) concluded that, with the current level of production, phosphate rock reserves that can be used for the production of fertilizer will be available for the next 300–400 years. However, bearing in mind that reserve figures are dynamic in nature, the quality of the remaining phosphate rock is decreasing and production costs are increasing, and the fact that P is a non-renewable resource, there should be a global effort to mine it more efficiently, and make efficient and sustainable use fertilizers from both inorganic and organic sources. Organic wastes and crop residues that are being produced in abundance in the cities and rural areas of SSA can also, when properly managed, be a supplementary source.

Sustainable management in agriculture requires that research discovers mechanisms in plants that enhance acquisition and exploit these adaptations to make plants more efficient at acquiring P, develop P-efficient germplasm (e.g., plants that are tolerant to low levels), and advance crop management schemes that increase the availability or conserve it in fertilizer.

Pools and Availability in the Soil

This element does not occur by itself in nature; it is always combined with other elements to form many different phosphates, some of which are very complex. Figure 5.3 is an adaptation from Cardoso and Kuyper (2006), showing pools in soils varying in availability. Pools with the lowest availability are the largest in Oxisols. This is a major constraint on agricultural productivity in highly weathered tropical

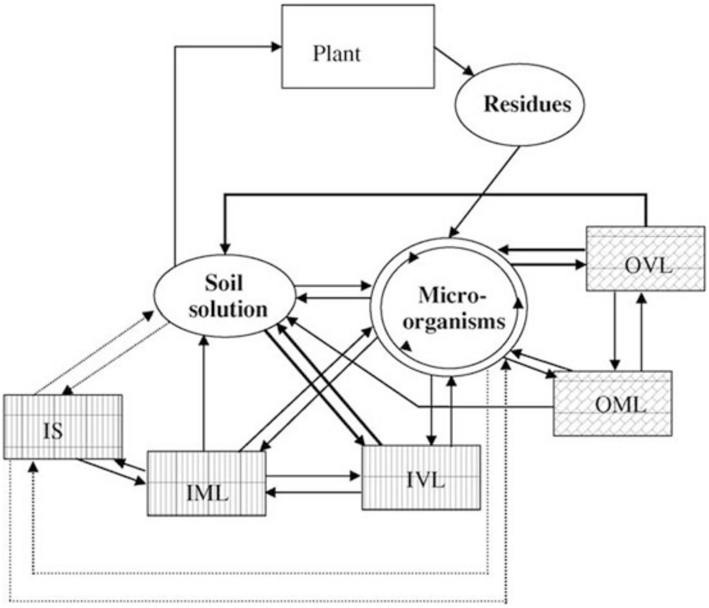

Fig. 5.3 General cycle of P in soils (*Source*: Cardoso and Kuyper 2006)
The P is apportioned into pools that vary in availability to plants. (*IVL*) Inorganic very labile, (*IML*) inorganic moderately labile, (*IS*) inorganic stable or inert, (*OVL*) organic very labile and (*OML*) organic moderately labile. Very labile can be considered available to the plants in short terms, for example to annual crops. Moderately labile is available to the plants in medium terms, for example, to perennial crops. Stable is only available in long term. Inert pool (Pi or Po occluded in the organic matter) was not included in the model because this pool may not be available at all. *Bold arrows* represent very labile pools and *dashed arrows* represent the stable or inert pools

soils. Deficiency is mainly caused by strong adsorption of the orthophosphates (H_2PO_4) to Al and Fe (hydro)oxides, which turns large proportions of total P into forms that are unavailable to plants. This limits the availability of inorganic P for plants, whether it is already contained in the soil or added as fertilizer. Furthermore, some tropical soils contain only small amounts of total P, with a relatively large proportion of this present in organic forms (Nziguheba and Bünemann 2005; Oberson and Joner 2005).

Deficiency of P is a factor limiting crop production in tropical and sub-tropical soils (Sanchez and Salinas 1981; Mokwuny et al. 1986; Fairhust et al. 1999). As mentioned earlier, correcting the deficiency with applications of fertilizer is not possible for most of the resource-poor farmers in the tropics and subtropics, especially on soils with high P-fixing capacity.

In a continent with a relatively rapid population growth, declining per capita food production, endowed for the most part with highly weathered, acidic soils with low nutrient status and where agriculture is mainly subsistence undertaken by resource-poor farmers, sustainable management of soil nutrients is crucial for sustained increased agricultural production. Conservation of P for enhanced crop productivity is essential. A lot of knowledge on the acquisition of P by biochemical means has been generated over the years (Shen et al. 2011) and this knowledge should not remain only as a scientific discovery, but should be made available for practical use on a wider scale.

Acquisition for Enhanced Crop Productivity

In view of the non-renewable nature of mineral phosphate resources, it is a prerequisite for the survival of life that man continues to explore and make efficient use of other sources of this essential element. Sustainable management in agriculture requires that plant biologists/breeders discover mechanisms in plants that enhance P acquisition and exploit these adaptations to make plants more efficient at acquiring soil P. In other words, it requires developing P-efficient germplasm, and advancing crop management schemes that increase the availability of P in the soil (Vance et al. 2003). Additionally, better nutrient management in the tropics, for example, can be achieved by making an increased use of the biological potential (Cardoso and Kuyper 2006). Wissuwa et al. (2009) made an extensive review on the novel approaches in plant breeding for root zone-related traits that are important in nutrient acquisition under nutrient deficient soil conditions. They concluded that for novel molecular approaches to make a significant contribution to breeding for rhizosphere-related traits it will be essential to narrow the gap between basic sciences and applied breeding through more interdisciplinary research that addresses rather than avoids the complexity of plant–soil interactions. In their review, Fess et al. (2011) emphasized the importance of breeding programmes focusing more on nutrient economy and local environmental fitness rather than on high performance varieties under high input systems. They further concluded that

Table 5.1 Effect of P-solubilizing fungus on yield and P-plant uptake, Adapted from Singh and Reddy (2011)

Treatments	Shoot biomass, g	Root biomass, g	Yield, g plot^{-1}	P concentration (mg kg^{-1}) in tissues		
				Grain	Shoots	Roots
Soil	31 ± 3c	3.1 ± 0.7b	1,731 ± 10d	91 ± 4c	72 ± 4b	69 ± 4c
Soil + P. oxalicum	31 ± 3c	3.3 ± 0.3b	1,797 ± 14c	149 ± 7b	130 ± 7a	98 ± 3b
Soil + RP	49 ± 2b	6.3 ± 1.9a	2,438 ± 23b	152 ± 4b	89 ± 5b	116 ± 7b
Soil + RP + P. oxalicum	55 ± 3a	6.4 ± 1.6a	3,100 ± 27a	178 ± 2a	140 ± 5a	156 ± 7a

Values sharing a common letter within the column are not significant at $p < 0.05$

by increasing the availability of superior varieties specifically bred to low-input systems, either through traditional or advanced breeding methods, agricultural sustainability and global resource management will be improved.

(a) **Exploiting the biological potential of increasing availability to arable crops**

Plants take up P in the orthophosphate (Pi) forms $H_2PO_4^-$ and HPO_4^{2-}, which occur in soil solutions at very low concentrations. These forms can be of inorganic or organic origin. The amount of organic P present in soils varies from 20 to 80 % of the total (Prasad and Power 1997; Schachtman et al. 1998). The cycling and availability of P in soils is controlled by a combination of biological (mineralization–immobilization) and chemical (adsorption–desorption and dissolution–precipitation) processes (Frossard et al. 2000). The mineralization of organic P plays an imperative role in the cycling of P in a farming system (Khan et al. 2009). These are processes controlled by microbial activity which, in turn, is dependent on the prevailing soil conditions. These, together with other biological processes such as the immobilization and turnover of microbial P seem to be the major processes regulating cycling and availability from plant residues in soils (McLaughlin et al. 1988).

A number of soil microorganisms possess solubilizing traits giving them the ability to mobilize sparingly soluble inorganic phosphates (Babana and Antoun 2007). The use of phosphate solubilizing bacteria as inoculants simultaneously increases uptake by the plant and the crop yield. Strains from the genera *Pseudomonas*, *Bacillus*, and *Rhizobium* are among the most powerful phosphate solubilizers (Rodríguez and Fraga 1999). Fungi such as *Penicillium oxalicum* have also been found to be effective in enhancing the fertilizer value of rock phosphate (Singh and Reddy 2011) as shown in Table 5.1.

In nature, most plant roots form mycorrhizal associations of one kind or another with fungi in soil, with the mycorrhizal fungi performing the function of root hairs. This association plays an important role in plant P nutrition (Lopez-Gutierrez et al. 2004) and yield improvements (Young et al. 1986; Quilambo et al. 2005). Nwaga et al. (2010) published data from trials under farm conditions that clearly demonstrated the positive effects of arbuscular mycorrhiza (AM) (Table 5.2.). Significant increases in grain yields (48–478 %) were recorded when crops were inoculated with selected strains of AM under extremely poor soil conditions.

Table 5.2 The response of various crops to inoculation by selected arbuscular mycorrhizal fungi under farm conditions in diverse sites in Cameroon

		Yield (t/ha)[b]			
Crop[a]	Locality	Uninoculated	Inoculated	Yield increase (%)	Soil type
Banana[c]	Yaoundé	2.50	11.25	438	Ultisol
Cowpea	Yaoundé	0.12	0.35	200	Oxisol
Groundnut	Yaoundé	0.83	1.98	137	Oxisol/Ultisol
Leek	Nkolbisson	0.85	4.58	438	Oxisol
Maize	Ebolowa	2.62	4.10	58	Oxisol
Mucuna[d]	Minkoameyos	4.68	7.41	58	Oxisol/Ultisol
Oil Palm[c]	Mbankomo	4.75	11.82	149	Ultisol
Pepper	Nkolbisson	1.98	3.62	86	Oxisol
Sorghum	Maroua	1.54	2.28	48	Vertisol
Soybean	Ngaoundéré	0.27	0.41	50	Oxisol/Ultisol
Tomato	Ebolowa	3.24	7.00	116	Oxisol
Yam[e]	Ekona	10.23	59.10	478	Andosol

Source: Nwaga et al. (2010)

[a] Complete block design using four replicates and at least 80 plant samples per treatment (except banana, oil palm and yam). Plants were inoculated with a mixed inoculum containing two or three MF strains belonging to the species Glomus clarum, Glomus intraradices and Gigaspora margarita

[b] Unless specified otherwise

[c] Measured yield parameter: bunch weight per plant

[d] Measured yield parameter: aboveground biomass at flowering

[e] Tuber weight under nursery conditions (gram per plant)

In addition to increasing the tolerance of some of the crops (e.g., maize) to low acidity and to toxic Al levels in Oxisols, the inoculation of AM also had several other beneficial effects including effects on P use efficiency.

This kind of mutualistic symbiosis between plant and fungus could be one of the most important and poorly understood processes for nutrient acquisition and plant growth in agriculture. The symbiotic interaction is localized in a root or root-like structure in which energy moves primarily from plant to fungus and inorganic resources move from fungus to plant (Allen 1991). The contribution of AM particularly to P acquisition may be direct or indirect. The direct effect is the consequence of the production of extracellular phosphatases and the access to distant sources otherwise not available to plants (Joner and Johansen 2000). The indirect effect is due to its extra-radical hyphae that are capable of absorbing and translocating nutrients and of exploring more soil volume (Joner and Jakobsen 1995; Singh and Kapoor 1998). Both effects can contribute greatly to plant P nutrition even in P deficient conditions (Joner and Jakobsen 1995). For soils that are low in P or have a high P fixation capacity, as in most of the soils of SSA, AM will contribute to the efficient use of the nutrient for increased crop production. In addition to plant nutrition, AM fungi play an important role in enhancing physical and biological soil quality (soil structure, the interactions with other beneficial soil organisms N-fixing rhizobia), and in improved protection against pathogens (Cardoso and Kuyper 2006).

As earlier stated, insoluble Al and Fe phosphates and strong sorption to Fe^{3+} (hydr)oxides remove P from the bioavailable pool, limiting net primary production in the weathered acid soils of both the temperate and tropical regions (Haynes and Mokolobate 2001; Peretyazhko and Sposito 2005). It has, however, been hypothesized that, as the moisture regime changes from dry to mesic to wet, periods of anoxic soil conditions increase in intensity and duration, causing a depletion of Fe^{3+} (hydr)oxides and a release of sorbed P. Organic matter decomposition is also slowed down, shifting the repository of soil P from minerals to humus. This was demonstrated in a laboratory incubation study (Peretyazhko and Sposito 2005) where anoxic conditions caused significant Fe^{2+} production and this Fe^{2+} production was positively correlated with the release of soluble P, consistent with the idea that the reduction of Fe^{3+} in the soil served to solubilize P, possibly through desorption processes mediated by subsequent bio-assimilation, precipitation and resorption. The solubilization of soil P in forest soils of the humid tropics, which can provide a valuable source to plants and microorganisms, has been related to fluctuating redox potential and the reduction of iron (Chacon et al. 2006). In valley bottoms of the humid tropics with frequent periods of inundation this process can be a valuable source of P.

(b) Integration of P-mobilizing plant species

One of the most promising agronomic measures for phosphorus management is the integration of P-mobilizing plant species into the cropping system (Vanlauwe et al. 2000; Horst et al. 2001). These plant species show the ability to uptake P from less labile forms and store it in the above-ground biomass, even in excess of their needs (Kahm et al. 1999). Culture of such species enhances the uptake of soil P from deeper layers and, by returning the plant residues, surface soil profiles could be enriched. Some crop species (e.g., certain bean lines) have the capacity to modify the rhizosphere through surface root architecture, stimulating increased root growth relative to shoot growth (Nielsen et al. 2001). Certain lowland rice varieties exude organic acids (Hoffland et al. 2006), to cope with P deficient soil conditions. Some maize varieties respond to low P status by increasing the number and length of lateral roots (Pérez-Torres et al. 2008) or by maintaining elongated root axes (Mollier and Pellerin 1999) possibly exploring localized patches of higher availability. Certain bean varieties develop longer basal root hairs, which can increase Pabsorption several-fold (Cisse and Amar 2000; Yan et al. 2004). Associations with mycorrhizae to mediate the availability of P to plants (Bucher 2007) have also been reported. An in-depth review of the subject can be found in Ramaekers et al. (2010).

Upon decomposition, organic P in the incorporated green manure tissues could provide relatively labile or available P to succeeding crops, thus providing a larger pool of mineralizable soil organic P to supplement soluble inorganic pools (Tiessen et al. 1994). Along with the mineralized P, organic acids are released, which may help dissolve soil mineral P (Sharpley and Smith 1989; Zaharah and Bah 1997). Carbon dioxide (CO_2) released during decomposition of green material forms carbonic acid (H_2CO_3) in the soil solution, which ultimately dissolves P minerals

Table 5.3 Phosphorus availability in bulk and rhizosphere soils of continuous sorghum and rotation sorghum soils from Fada without N application at 57 days after sowing

	Phosphorus fraction			
	Total (P*t*)	H_2SO_4	Organic (P*o*)	Bray (P*b*)
Soil type	(mg P kg^{-1} soil)			
Rotation without plant	44.1	19.7	24.7	6.3
Continuous without plant	37.0	16.0	21.0	4.9
Rotation rhizosphere	45.0	15.3	29.7	5.8
Continuous rhizosphere	38.8	13.8	25.0	2.7
Rotation bulk soil	37.8	15.2	22.7	3.9
Continuous bulk soil	33.8	12.7	21.2	2.9
SED[a]	**1.08**	**1.12**	**1.42**	**0.31**
$P > F$[b]: *System*	*0.009*	*0.390*	*<0.001*	*<0.001*
$P > F$[b]: *Location*	*0.001*	*0.296*	*0.029*	*0.015*
$P > F$[b]: *System × Location*	*0.378*	*0.512*	*0.871*	*0.004*

Source: Alvey et al. (2001)

[a] Standard error of the difference

[b] Probability of a treatment effect (significance level)

in soils, thus increasing availability for plants (Tisdale et al. 1985). Cavigelli and Thien (2003) reported from a pot study that the incorporation of green manure crops into soil may increase bioavailability for succeeding crops. Pypers et al. (2005) reported from a field core incubation experiment that both P deficiency and Al toxicity can be amended through green manuring. Studying P deficient soils of the West African Sahel, Alvey et al. (2001) showed that legume–cereal rotations had significant positive effects on phosphate availability (Table 5.3), which in turn triggered improved cereal growth.

Li et al. (2007) reported that intercropping, which grows two or more crop species on the same piece of land at the same time, can increase grain yields greatly (Table 5.4.). Their investigations indicated that the large increases for maize, a crop species that has a high requirement for P, resulted from a rhizosphere effect of faba bean on maize, even when P was provided in an insoluble form. This was attributable to, what was termed, the interspecific facilitation between the intercropped species (maize and faba beans).

(c) Integrated soil fertility management (ISFM)

Integrated soil fertility management (ISFM) farming practices involve the integration of a range of actions that will result in raising productivity levels while maintaining the natural resource base. ISFM has been adopted by Tropical Soil Biology and Fertility (TSBF), its African Network (AfNet) and various other organizations as the paradigm for tropical soil fertility management research and development (Vanlauwe 2004). Its basic focus is on sustainability, creating a system able to provide adequate, affordable food, feed and fibre supplies in a

Table 5.4 Biomass and grain yields (kg/ha) of intercropped maize and faba bean with and without root barriers under field conditions (Field Study 2), (Li et al. 2007)

Crop	Solid barrier	Mesh barrier	No barrier	*F*(2,30)	*P*
Grain yield					
Maize	$5{,}311^{b}$	$5{,}341^{b}$	$6{,}722^{a}$	20.32	<0.0001
Faba bean	$4{,}176^{b}$	$4{,}392^{b}$	$5{,}527^{a}$	10.81	0.0003
Above-ground biomass					
Maize	$12{,}560^{b}$	$12{,}525^{b}$	$15{,}783^{a}$	21.04	<0.0001
Faba bean	$9{,}873^{c}$	$11{,}027^{ab}$	$12{,}468^{a}$	6.10	0.006

Values for grain yield are averages of all inoculations with rhizobium (two treatments), mycorrhiza (two treatments), and with four replicates ($n = 16$), because there was no significant response to the inoculations

$^{a,\ b}$Values in the same row followed by different superscript letters are significantly different ($P < 0.05$)

profitable manner without being detrimental to the environment. Key aspects of the approach include the following:

- Replenishing soil nutrient pools
- Maximizing on-farm recycling of nutrients
- Reducing nutrient losses to the environment
- Improving the efficiency of external inputs

Much of the above interventions for nutrient P management are aspects of ISFM. Several scientists have reported the effect of organic amendments on crop yield increases partly due to effects of soil organic carbon. Bationo et al. (2007) reported a large positive and additive effect of applying crop residues and mineral fertilizer on the yield of pearl millet from a long-term experiment carried out in the West African Sahel (Table 5.4). The results also indicated that for these soils, the potential for continuous millet production is very limited in the absence of soil amendments. Gangwar et al. (2006) recorded increased SOC content and availability of P and concluded that reduced tillage and the in situ incorporation of crop residues at 5 Mg ha^{-1} along with 150 kg N ha^{-1} were optimal to achieve a higher yield of wheat after rice in sandy loam soils (Table 5.5).

Combining organic and inorganic amendments is one of the most effective strategies in improving soil nutritional status, particularly in the humid tropics. Nabahungu et al. (2007) reported that a combination of green manures (*Tithonia* and *Tephrosia* spp.), phosphate rock and limestone ameliorated Al toxicity and increased the P, K, Ca and Mg status of the acid soils of Tonga, Rwanda; high yields and substantial residual effects were obtained from an amendment comprising a mixture of the three Similar observations were made by Nziguheba et al. (2004) who reported an added maize yield of 32 % by the addition of sole *Tithonia* compared with the addition of fertilizers alone, and an added 41 % yield for *Tithonia* in the residual phase compared with fertilizers alone. Management practices that combine P-enhancing and low-P tolerant crop species with inorganic inputs should offer a sustainable strategy for ameliorating problems related to P deficient soils in SSA.

Table 5.5 Effect of crop residue and fertilizer on pearl millet grain and stover yields at Sadore, Niger (*Source*: Bationo et al. 2007)

	Grain yield (kg ha^{-1})				Stover yield (kg ha^{-1})			
Treatment	1983	1984	1985	1986	1983	1984	1985	1986
Control	280	215	160	75	*NA*	900	1,100	1,030
Crop residue (no fertilizer)	400	370	770	745	*NA*	1,175	2,950	2,880
Fertilizer (no crop residue)	1,040	460	1,030	815	*NA*	1,175	3,540	3,420
Crop residue plus fertilizer	1,210	390	1,940	1,530	*NA*	1,300	6,650	5,690
$LSD_{0.05}$	*260*	*210*	*180*	*200*		*530*	*650*	*870*

NA not available

Conclusion

Without P, an essential element, life will not exist. Being a non-renewable resource, it is of no consequence whether reserves lasting centuries exist or not. The element has to be conserved and prudently managed, and this is valid whether we live in the industrialized or developing world. In the context of the humid tropics, and indeed of SSA, slash and burn agriculture, still practised in many places, is not sustainable. It counteracts most of the objectives of an integrated management system. Management of P will involve the sound management of on-farm organic resources (green manures, cover crops, crop residues, farmyard manure etc.) and the application of biotechnology. These have the potential to complement mineral fertilizers where they are not readily accessible, and even to reduce the amounts required to improve crop yields. The advantages offered by biological approaches, as indicated in this paper, must be exploited to a greater extent. Governments should take the responsibility of making available to producers all of the information and knowledge which contribute to increased agricultural production and food security. Both challenges and opportunities are implicit in this.

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Part II
System Components

Chapter 6

A Decade of Agricultural Research in Rwanda: Achievements and the Way Forward

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Abstract Agricultural research is the engine driving agricultural growth in Rwanda which has resulted in the country being food secure over the last two years (2010–2011). Research has developed and released high yielding, disease and pest resistant crop varieties, animal breeds/genotypes and other improved technologies. These have resulted in increased productivity/unit area while protecting the natural resource base. In line with national policies, combating malnutrition and extreme poverty has also been a priority for agricultural research. This paper highlights the different components of research responsible for the observed growth in the sector in Rwanda over the period from 2001 to 2011. This information could be useful to other countries in the region pursuing similar goals of improving food production for their populations.

Keywords Technology development • Food security • Nutrition • Genetic conservation

Introduction

Agriculture is the backbone of the Rwandan economy, contributing 34 % of the national GDP, and employs over 80 % of the population. The realization of the Vision 2020, Millennium Development Goals and the Economic Development and Poverty Reduction Strategy is heavily dependent on agriculture. The sector faces various distinctive challenges, most notably the fact that the system is extremely land constrained. Rwanda has one of the highest population densities in Africa; the result is smallholder farming, with an average land holding 0.7 ha/household (MINAGRI 2009).

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Research has been recognized as an indispensable tool in the development of the sector and the fight against hunger and poverty. Until July 2011, the Rwanda Agricultural Research Institute (ISAR) was mandated to conduct scientific and technical development of agricultural and animal resources in Rwanda to improve the livelihoods of low-income farmers. ISAR conducted research and promoted technologies in crops, livestock, forestry, agro-forestry, post-harvest management, land conservation and water management. Furthermore, the Institute partnered with relevant institutions to disseminate results to the intended beneficiaries. Research has made tremendous achievements over time in contributing to the modernization of agriculture in Rwanda in line with national, regional and international development policies over the past 10 years. Research activities have contributed to the improvement of food security, nutrition and sustenance of the natural resource base.

The research was conducted through programmes and implemented through zones covering the different agro-ecological regions of the country. Recent government restructuring has seen the merging of ISAR with two other extension institutions to form Rwanda Agriculture Board (RAB), with the vision to create greater synergies between research and extension. Agricultural research has been operating within this new organization since July 2011.

The objective of this paper is to present the outputs that have been achieved in the last decade (2001–2011).

Development and Dissemination of Improved Crop Varieties

The decade has seen major radical changes in agricultural development; new varieties of priority crops, including maize, beans, cassava and rice, have been developed and disseminated (Fig. 6.1).

Research efforts on maize have targeted several constraints including the low yield potential of traditional varieties, and environmental and biotic stresses. Ten varieties for the mid-altitudes and one for highlands have been released. The mid-altitude varieties include seven open pollinated varieties: Kigega (Z6M07), Ndaruhutse (Pool 32) (Ngaboyisonga 2003), ISARM081, ISARM101, ISARM102, ISARM103, ISARM104, and three hybrid varieties: RHM101, RHM102 and RHM103. The highland variety is ISARH071. Emphasis was given to the mid-altitudes because of the rapid development and expansion of the maize crop in these areas (Ngaboyisonga et al. 2007).

Kigega (ZM607) has become a very popular variety and provides more than 60 % of the national production of maize grain because of its resistance to foliar diseases. It has a high yield potential that can go up to 7 t/ha under good management. ISARM081 is the first Quality Protein Maize (QPM) variety released in Rwanda. It is an extra-early maturing variety (90 days, on average) for Rwandan conditions, resistant to Maize Streak Virus Disease (MSVD) and has high levels of lysine (0.45 %) and tryptophan (0.11 %) in the grain. The three hybrid maize

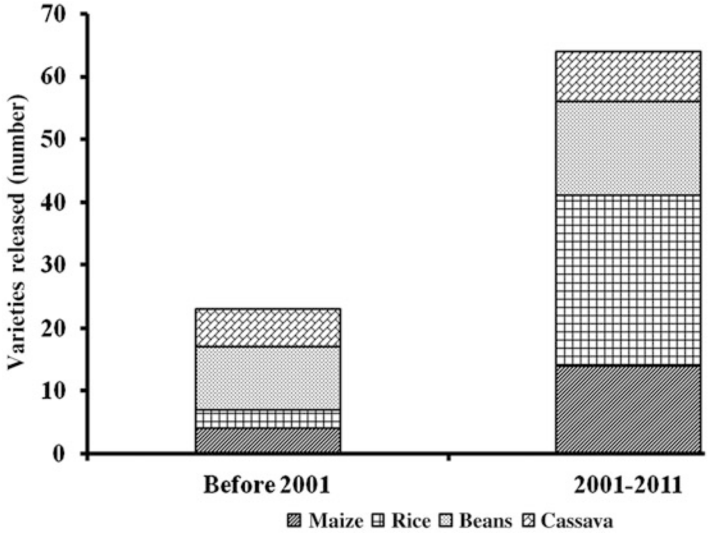

Fig. 6.1 Comparison of the number of varieties released before 2001 with the number released in the last decade (2001–2010) for four major crops (*Source:* Adapted from ISAR unpublished data)

varieties, RHM101, RHM102 and RHM103, were developed from CIMMYT's inbred lines and provide useful traits, such as drought tolerance in RHM102 and QPM in RHM103.

Fifteen bean varieties were developed and released in 2011. These included three climbers for the mid-altitudes (MAC9, MAC49 and MAC44), four climbers for the highlands (RMV2070, Gasirida, RWV1129 and CAB2) and nine bush types for all ecologies (RWR2245, RWR1180, RWR2154, RWR3042, RWR2076, Pyramide, RWR2340, SER16 and SER30). The new climbing beans are steadily gaining popularity because of their high yields (5 t/ha), early maturity and resistance to diseases such as Angular Leaf Spots (ALS) and root rots. The three varieties (MAC49, MAC 9 and MAC44) were the first climbers developed and released for the mid-altitudes.

In 2010, cassava was grown on 197,394 ha and ranked third after beans (319,252 ha) and banana (216,953 ha) (FAO 2011). In 2002, the cassava crop was seriously affected by Cassava Mosaic Disease (CMD). To respond to this, eight new CMD resistant varieties have been released and their adoption by farmers has revitalized cassava production in the country.

Rice research efforts in Rwanda have been focusing on tolerance for low temperatures and moisture stress for increased productivity. Major achievements comprise the release of three varieties, IR64, WAT54 and IR65192-4B-17-3, for low-altitude rice schemes and four varieties, Gakire, Instinzi, Instindagirabigega and WAB543-45-2, for the mid-altitudes. These varieties have quality commercial grain features, notably, long, slender and translucent grains.

Crop Protection

One of the major challenges facing agricultural production and productivity in Rwanda is the enormous crop losses caused by pests and diseases (ISAR unpublished data). Research has approached crop diseases and pest management on two fronts: pre- and post-harvest crop protection. Several approaches have been undertaken ranging from on-station to on-farm trials, with farmers' participation. Initiatives such as Farmer Field Schools have been used to design Integrated Pest Management (IPM) technologies that are easily adopted by farmers. The collaboration of local scientists on crop protection projects with regional and international research organizations such as the centres in the Consultative Group on International Agricultural Research (CGIAR) has tremendously boosted the development of IPM technology for various crops in the country.

Although the list of "pathosystems" and "entomosystems" in Rwanda is quite long, there are major biotic constraints, regarded as economically important, that are worth mentioning. Research has concentrated on breeding for resistance/tolerance to different diseases.

Maize researchers have successfully developed varieties (ISARH071, ISARHM081, among others) for resistance to MSVD and *Turcicum* Leaf Blight Disease caused by the fungus *Exserohilum turcicum* (Pass.) Leo and Suggs. Rice and wheat germplasm have also been introduced and tested for resistance/tolerance to foliar diseases such as rusts. Beans have received a great deal of attention as this is an important protein crop for the country. Research projects in this programme have primarily dealt with breeding for disease resistance (Musoni et al. 2010; Nzungize et al. 2011), fertilizer responses and agronomic management, among others. Breeding has resulted in the release of a good number of varieties of beans, and this varietal resource has benefited and will continue to benefit the entire East and Central African region, especially in climbing beans as research on this crop in the region is mainly conducted in Rwanda (Ogodo 2010). Another challenge has been viral diseases of cassava, particularly CMD (Legg et al. 2001) and Cassava Brown Streak Disease which had threatened the production of this staple crop. Other notable crop protection research activities have involved screening germplasm for Fusarium wilt of banana, resulting in two resistant/tolerant cultivars (FHIA 17 and FHIA 25). Research has also been conducted on tolerance to the banana nematode (Gaidashova et al. 2008), as well as diagnostics and surveillance techniques (Gaidashova 2009).

Post-harvest crop protection research includes the biological control of the devastating maize Larger Grain Borer (*Prostephanus truncatus*). Laboratory studies involving biocontrol agents showed that *Teretrius nigrescens* significantly reduced the borer population. This is in agreement with results from other studies (for example, Hill et al. 2003). The natural enemy was released to the field where infestation starts, and initial surveillance indicated that the population was successfully established and able to significantly reduce the pest population (Unpublished ISAR data).

Genetic Resource Conservation

During the past 10 years, conservation efforts on crop varieties in Rwanda were mostly concentrated on coffee and banana. The coffee gene bank of about 180 accessions has been established in three different research stations. The banana germplasm collection consists of a comprehensive inventory of the existing banana cultivars; 110 banana varieties are maintained in a field gene bank at Rubona Research Station. Apart from its conservation value, this germplasm centre is also used as a source of planting material.

The *ex situ* arboretum at Ruhande (Southern Province) has a collection of 205 species of forest and agro-forestry species including 21 indigenous species, notably *Croton megalocarpus, Syzygium parvifolium, Entandrophragma excelsum, Markhamia lutea and Pterygota mildbraedii*. The arboretum is of national, regional and international importance as a reserve for forest and agro-forestry tree seeds.

The Ankole longhorn is the major indigenous cattle genetic resource in Rwanda; however, it is threatened by uncontrolled cross-breeding and the inevitable introduction of high yielding breeds. Over the last 5 years, however, research efforts have endeavoured to establish a herd of 310 pure Ankole cattle (ISAR unpublished data). The key gaps have been in increasing the herd size to at least the 600 elite cows required for a sustainable conservation strategy.

Animal Genetic Improvement

Improvement of animal genetic resources through a rational combination of local and exotic breeds was identified as a suitable strategy for upgrading local breeds, especially cattle and goats. This strategy included breed synthesis (cross-breeding) by using semen through artificial insemination and breed substitution (MINAGRI 2009).

Establishment of a goat breeding programme started with a baseline study to map existing goat genotypes and to identify key phenotypic features. Significant variability was found in indigenous goat characteristics and needed a strategy for improvement and conservation (Manzi et al. 2011). East African indigenous small goats were improved using imported bucks (e.g., Galla goat, Boer goat). A nucleus scheme of 111 pure Boer breed and 68 pure Galla breed was established for the improvement of indigenous goats.

Cross-breeding for cattle aimed to cope with an increased demand for milk. A review of progeny records for 10 years showed that 13 genotypes were generated. They were clustered into double, triple, and four-way crossed Friesian and Jersey crosses with the base Ankole cattle population. These genotypes (497 crossbred cows) were disseminated to small households under the One Cow per Poor Farmer programme. The review clearly depicted the need for improvement in the establishment and archiving of breeding records.

The Multiple Ovulation and Embryo Transfer (MOET) technique was introduced and four offspring were produced (Kayitesi et al. 2011). The establishment of a prudent balance between pure indigenous and exotic cattle and the cross-breeds for milk production was assisted by reproduction techniques.

Animal Nutrition

In the last decade, the priority for animal feeds and feeding was to introduce new high yielding forage species adapted to local conditions (Barahenda 2006). *Brachiaria* hybrid cultivar Mulato II, known for its drought tolerance and resistance to the spittlebug (*Aphrophora* sp.), was introduced and evaluated (Mutimura and Everson 2012).

Research on crop residues identified that feeding cereal straw could meet 40–80 % of the Metabolisable Energy for maintenance (ME_m) requirement for dairy cows of landless farmers (Ebong 2010). Evaluation of feed resources with farmers' participation was also used to assess the availability of feeds and showed that the shortage of feed resources was more pronounced in those areas with low rainfall and acidic soils than in the rest of the country (Mutimura and Everson 2011). Rwanda has contributed to the regional feed database for the Eastern and Central African region produced for livestock stakeholders (Mutimura et al. 2010).

Animal Health

Animal health research in Rwanda has focused on reproductive diseases, helminthes and infectious diseases of a trans-boundary nature. Reproductive performance analysis at the farm level showed that the major problems for livestock dairy farmers were dystocia (37 %) and retained placenta (33 %) (Biryomumaisho et al. 2011). Tick-borne diseases (27.6 %) and gastrointestinal parasites (18.4 %) were among the most prevalent general diseases reported to constrain reproduction in Rwanda (Chatikobo et al. 2009). Another reproductive disease that dairy farmers encountered was bovine brucellosis which was detected as the prevalent reproductive disease in the country. Biryomumaisho et al. (2011) found that ticks at Songa research station had developed resistance to cypermethrin®, and similar incidents have been reported in the Eastern Province.

The prevalence of brucellosis in the eastern region was 2.6 %; no case was observed in the western zone of Rwanda, mainly because the popular reproductive method in the west is artificial insemination while the use of bulls is still prevalent in the east (Biryomumaisho et al. 2011). Another zoonosis under current study is the prevalence of cysticercosis in pigs and neurocysticercosis in humans. Preliminary results on slaughter-house pigs showed an 8.5 % level of prevalence of porcine cysticercosis in the southern zone.

The molecular characterization of contagious bovine pleuro-pneumonia (CBPP) was performed using polymerase chain reaction (PCR) and loop mediated isothermal amplification (LAMP) for detecting *Mycoplasma* antigens in blood and body fluids, especially in asymptomatic cases (Enyaru et al. 2012). The study found that the causative agent of CBPP in the country was *Mycoplasma mycoides* spp. *mycoides* SC (small colony). Current diagnostic methods (Complement Fixation Test = CFT) and competitive ELISA (cELISA) were not sufficiently sensitive to diagnose the pathogens with sufficient precision beyond confirming suspicious herds (Enyaru et al. 2012). LAMP was found to be a more useful technique than the existing ELISA technique for the rapid and accurate diagnosis of infected animals for control of spread and elimination.

Soil and Water Management

Major outputs of research on soil and water management included Rain Water Harvesting (RWH). Small runoff systems have been tested in Bugesera and Nyagatare districts and successfully scaled out in Kirehe and Ngoma sectors, with more than 500 systems introduced. The established RWH system in Nyagatare is in the process of being expanded to cover 21,000 ha. The maximum storage was 1,714 m^3 of water, which represented less than 50 % of the total storage capacity set at a height of 1.5 m. The relation of rainfall to runoff confirms a collection of runoff that was below expectations (Kabiligi et al. in press). Eighty percent of surveyed households surrounding the RWH structure used water from the reservoir, with an average of 17 ℓ/day/household.

Integrated Soil Fertility Management (ISFM)

The most serious problems in Soil Fertility Management in Rwanda have been soil acidity, aluminium (Al) toxicity and deficiencies of P, K and N (Beenart 1999). Studies conducted to assess the effects of limestone, Minjingu Phosphate Rock (MPR) and green manures (GMs) on maize and bean yields, soil properties and nutrient uptake showed that GMs improved the supply of N and K; limestone played a significant role in reducing exchangeable Al (Nabahungu et al. 2007). A significant contribution of P was from MPR. A combination of MPR, GMs and limestone supplied ample amounts of N, P, K, Ca, Mg and reduced exchangeable Al and hence resulted in high yields. However, high rates of limestone decreased dry matter yield and nutrient uptake in the treatment with three amendments. In general, *Tithonia* when applied as a GM gave higher yields than *Tephrosia*. The results also indicated that a combination of low rates of limestone, MPR and GMs is the best strategy in improving the productivity of the acidic soils in Rwanda. Other studies conducted in Rwanda have shown that limestone has the capacity of increasing soil pH and hence reducing Al toxicity (Lunze et al. 2012). Furthermore, it has been observed that the use of lime in combination with organic and inorganic fertilizers is the most efficient technique for addressing the problem of soil acidity and enhancing soil fertility in Rwanda (Mukuralinda et al. 2010).

Field experiments conducted in Butare to assess the effect of *Tithonia diversifolia* biomass and maize residues on the yield of climbing bean (Var. G2331) and selected soil properties demonstrated that there is a significant positive effect ($P < 0.01$) on the yield of climbing beans at the two sites used in the study. The highest yield increase was achieved from the treatment of *Tithonia* plus maize residues and TSP (3.3 t/ha) (Nabahungu et al. 2011). The high performance of the *Tithonia* application on bean yield confirms its capacity to increase production compared with inorganic fertilizers at equal rates of P. Research data on soil fertility management in major bean growing areas were used to develop a comprehensive decision support system for use by farmers and extension workers (Lunze et al. 2012).

Improved Agricultural Productivity Through Fertilizer Use and Biological N Fixation

A study on fertilizer use and biological N-fixation showed that productivity and N-fixation of legumes in rotation with maize varied greatly between different eco-niches (wetland, foothill and hillside) within and between wetlands (Nabahungu 2012). This suggested that different technologies of ISFM were needed for the improvement of productivity of smallholder farms in different agro-ecological zones and eco-niches in Rwanda. Higher productivity of shoot dry matter, legume grain, fixed N and subsequent maize grain was recorded in both wetland and foothill plots compared with the hillside plots. The soybean and bean varieties studied were capable of fixing atmospheric N_2 on farms without artificial inoculation using rhizobia. However, the quantity of fixed N was much lower (<30 kg ha^{-1}) than quantities (>60 kg ha^{-1}) cited in the literature (Nabahungu and Visser 2011).

Forestry and Agro-forestry Research

Exotic and indigenous tree species adapted to different agro-ecological zones have been selected and are now being used in national afforestation and reforestation programmes in the country. However, most of the afforested lands in Rwanda are covered with Eucalyptus species. There are now about 69 eucalyptus species in Rwanda; all of them have been conserved *ex situ* in Ruhande Arboretum but only 10 species were planted countrywide across different agro-ecological zones (MINIRENA 2008). Due to the negative effects of many Eucalyptus species on soils and soil water reserves, forestry research has selected five species that are used for afforestation activities: *E. camaldulensis, E. globulus, E. maidenii, E. microcorys and E. tereticornis.*

ISAR, in collaboration with the National University of Rwanda and the Ministry of Natural Resources, conducted a national inventory which determined the actual standing stock of forest resources and identified sites for afforestation, estimated at 3 % without including agro-forestry systems (MINIRENA 2007).

Most of tree seeds used in the country are acquired from the Tree Seed Centre. More than 5 t of tree seeds are being supplied annually to key players in the national afforestation programme, the highest seed demand has been from local Government (52 %) and projects (34 %) (AFF 2011).

Biotechnology

Biotechnology research at ISAR was initiated in 2004 as a measure of responding to the downward trend of productivity by exploring alternatives to conventional agricultural methods. The biotechnology facilities have been vital in aiding scientists from different research programmes to conduct cutting-edge research in disease characterization (both plant and animal) and plant genotyping using molecular biology techniques. Biotechnology research has also contributed to the national capacity to respond to the considerable demand in the country for quality planting material to rejuvenate highly genetically-eroded and diseased material. Scientists embarked on research to develop and optimize tissue culture protocols for different crops and plants. As a result, protocols for the *in vitro* regeneration of coffee (using somatic embryogenesis), potato, banana, pineapple and sweet potato were successfully developed and the generation of disease-free plantlets of these crops has attained a mass production level (unpublished data). An aeroponics system has been designed to support the potato *in vitro* laboratory to further accelerate the production of disease-free mini-tubers to solve the crisis in the potato sector that was characterized by a supply of only about 4 % of the required seeds (Senkesha, personal communication). Recently, other crop regeneration protocols have been successfully developed and optimized: vanilla (Mushimiyimana et al. 2011a), cassava (Mushimiyimana et al. 2011b), tree tomato (Waweru et al. 2011) and passion fruit. Other protocols, including those for bamboo and pyrethrum, are still under development.

Research Staff Capacity Building

Since 2001, there has been a deliberate effort to build the capacity of agricultural researchers in the country. Currently, research staffing stands at 7 with PhD, 61 with MSc, 90 with BSc and there are 77 technicians. The researcher: technician ratio is still below the required target of 1:2. Furthermore, a staff competence indicator is the number of PhDs that are actively engaged in research, hence there is a critical need to further build the capacity and numbers of scientists.

Conclusion

Agricultural research in Rwanda has played a key role in raising the nutritional levels of the Rwandan population and guaranteeing food security to the nation. In particular, the development and release of new, improved high yielding varieties in priority crops have helped to support the Crop Intensification Programme (CIP). The capacity of the Animal Production Program to support the *Girinka* policy (One cow per poor family) through improved breeds, nutrition and health has been established. However, several challenges still need to be overcome, particularly the effective and timely transfer of technologies to end users. It is envisioned that the synergies created through merging research and extension will accelerate technology transfer and uptake.

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Chapter 7
Do Commercial Biological and Chemical Products Increase Crop Yields and Economic Returns Under Smallholder Farmer Conditions?

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Abstract During recent decennia, new commercial products have appeared on the market as alternatives to common fertilizers. While some of these products are based on well-established technologies, such as rhizobium inoculation, others have not been subjected to scientific scrutiny. During 3 years, we evaluated over 80 of these new products, including microbial inoculants and chemical products on major legume, cereal and banana crops across diverse agro-ecological conditions in Ethiopia, Nigeria and Kenya in the laboratory, greenhouse and field conditions. Amongst the rhizobial inoculants, several products from different companies were found very effective in increasing nodule biomass on soybean and increasing grain yield by up to 30 %, and benefit-cost ratio of up to 5.0 realized. Except for tissue cultured bananas, the effect of arbuscular mycorrhizal fungal (AMF) inoculants was less evident with optimal yield of legumes realized with co-inoculation with P

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solubilizing bacteria and when supplemented with inorganic fertilizer such as DAP. Other products containing *Trichoderma* or *Bacillus* spp. improved growth under field conditions, soil-dependent growth improvements of over 40 % in tissue culture bananas. The potential of products to reduce soil pathogenic rhizosphere organisms, particularly *Fusarium*, was also observed. Chemical products evaluated, special attention was given to alternative P fertilizers such as leaf sprays, seed coatings and conditioners with humic acids. The effect on cereals depended on the crop, the soil and accompanying agronomic measures. Benefit-cost ratios were favorable for seed P coating Teprosyn, because this is a fairly inexpensive treatment (US $ 3 ha^{-1}). Results demonstrate economic returns of US$ 4 for every dollar invested for soybean production and US $ 4.6 for every dollar invested in maize production. The Net benefit of US $ of 5,265 for Rhizatech matches benefits of US $ 5,115 derived from Conventional practice with half investment of US $ 62 compared to US $ 135. The potential for biological and chemical commercial products is evident and the need for continued evaluation. Smallholders may benefit from good quality products that are correctly applied to the appropriate crop under appropriate soil and crop management.

Keywords Agro-inputs • Commercial products • Soil management

Introduction

Knowledge on soil management practices and technologies accumulated in the last 20 years combined with crop improvement and plant health at farmers' level can confidently address problems associated with intensification of major cropping

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systems of Sub Saharan Africa (SSA) (Sanginga et al. 2003; Sanginga and Woomer 2009). Technological breakthroughs in soil fertility are emerging amongst which are biological and chemical interventions, being commercialized by private companies and now accessible to small holder farmers. Some products, such as rhizobial (Giller 2001) and mycorrhizal (Hamel and Plenchette 2007; Sieverding 1991) inoculants have been proven to substantially enhance the productivity of specific crops. However, the proliferation of new chemical and biological products appearing on the market in SSA that claim major impact in increasing crop productivity are of major concern.

The porous borders, weak regulations, lack of institutional capacity in infrastructure and human capacity in regulatory agencies can be cited as the main factor for proliferation of the low quality products. Developed countries such as Canada, France, United Kingdom, United States of America, Australia and New Zealand have legislations and regulations on biofertilizer and biopesticides enforced (Catroux et al. 2001; Herridge et al. 2002). In Africa, the Biosafety regulations address only Genetically Modified Organisms (GMO) while strict measures are enforced on importation of plant materials and soils. The presence and acceptability of products by farmers also indicates the farmers' interest in new interventions to improve yield and a failure of existing proven interventions to do so. Quality products are crucial to guarantee farmer confidence and adoption of new technologies. Contaminants present in products are reported to have detrimental effects on rhizobia and their effect on man, plants and the environment is not known (Olsen et al. 1994; Bashan 1998).

Currently, private companies are commercializing these industrial agricultural products and seed technologies, and have displayed their success through visual observations and yield improvements in demonstration fields on various crops in several African countries. Farming systems, farm typologies and soil conditions in Africa are largely heterogeneous (Vanlauwe et al. 2006) and therefore products evaluated outside the continent may not reflect similar performance. A rigorous, in-depth scientific evaluation of these products that confirms the alleged yield improvements is therefore still lacking, and the products demand rigorous testing to verify whether they can fulfill the claims of the manufacturer. To prevent the proliferation of underperforming products and stimulate farmer adoption of emerging technologies, there is need to assemble approaches that can be adopted to evaluate products independently so as to get rid of underperforming products. Testing was conducted by CIAT in collaboration with IITA, EIAR and Moi Chepkoilel University working towards approaches from laboratory, greenhouse, field and economic evaluation that can be adopted to determine quality and efficacy of products and recommend their suitability for small holder farmers. This paper presents some of these approaches.

Materials and Methods

Classification of Products Based on Mode of Action

Products developed by private companies were classified based on their mode of action as follows: Category I: rhizobial Inoculants (Biological Nitrogen Fixation) (22 products) which included best-bet locally-isolated promiscuous bradyrhizobial strains and available commercial inoculants obtained from private companies, Category II: other (non-rhizobial) microbiological products which include microorganisms that are beneficial to plant growth through disease suppression, production of metabolites promoting root development or general plant growth, or improving the plant's ability to acquire less mobile nutrients (particularly P and Zn). Examples are *Trichoderma* (Eco-T), *Bacillus* spp., mycorrhizal inoculants and free living nitrogen fixing microorganisms such as *Azospirillum*, *Azotobacter*. These were further spilt to Category II A (free living nitrogen fixing) and Category II B, the remaining non rhizobial microbiological products. Category III: other non-microbial products and seed treatment technologies: These include non-microbial products that stimulate the microbial activity in the rhizosphere, and are so indirectly beneficial to crops. The total number of products collected for evaluation were as follows: Category I- 22, Category II B-26, Category II A & B-18 and Category III- 18.

Laboratory, Greenhouse and Field Approach Used in the Evaluation of Products

A large number of products were evaluated in the laboratory by quantitative and qualitative methods to confirm the presence of declared strains. The plate count method using Yeast Extract Mannitol Agar (YEMA) and Malassez cell techniques were used on rhizobial and non-rhizobial bacterial products (Reasoner and Geldreich 1985; Claus 1989; Sakr et al. 2009; Thuita et al. 2012). Spore extraction techniques and spore counts and colonization (Jenkins 1964; Koske and Gemma 1989; Schenck and Perez 1990), serial dilution plating with malt extract (MEA) (Johnson et al. 1959) and the most probable number (MPN) methods were used (Brockwell 1963; Moreira et al. 2008). Molecular methods was applied to further confirm the composition and number of strains in the products (Wilson 1987; Altschul et al. 1990; Turner et al. 1999) with sequencing done at Bioscience East and Central Africa (BecA) ILRI-Hub, Nairobi and the strains isolated from the inoculants were identified by sequencing followed by BLAST (Basic Local Alignment Search Tool) program (Altschul et al. 1990). Laboratory analysis was undertaken at the CIAT-TSBF, IITA and the Agriculture and Agri-Food Laboratory, Ottawa, Ontario, Canada. Category III products were subjected to laboratory analysis to quantify the nutrient element concentrations for organic and mineral content. Only products confirmed in the laboratory to have content indicated on the label proceeded for greenhouse screening. Greenhouse evaluation was undertaken on all products that were confirmed to have bacterial and/or fungal composition as indicated on the labels. This was conducted by comparison of greenhouse with plants established in soils collected from action sites in mandate areas of each country.

Products that increased growth by more than 30 % compared to the control and or normal conventional practice proceeded for field evaluation. The field evaluation was done as a basis for integrating products into ISFM technologies under demonstration and farmer participatory trials.

Benefit-cost analysis of effective products, Legumefix (Category I), Rhizatech (Category IIB) and seed coating Teprosyn (Category III) were evaluated and the most profitable to farmers are presented. The Dominance analysis was conducted for tissue culture banana to verify alternative interventions to nursery management of TC bananas.

Results and Discussion

Laboratory Characterization of Products

Laboratory analysis with respect to Category I inoculants indicated the bacterial concentrations (cells/ml) in the inoculants to be $>10^9$ for 1495MAR; 3.32×10^8 for TSBF-Mixture; 1.96×10^7 for Legumefix; 4×10^5 for Histick. The observations made were much less than the specifications ($>10^9$ and $>2 \times 10^9$ cells/g) given by the manufacturers for Legumefix and Histick, respectively (Atieno 2012; Atieno et al. 2012). In several products, more strains that had not been declared on the labels were isolated than expected (Atieno 2012; Atieno et al. 2012; Faye 2013) (Table 7.1).

Results showed 51 % of Category I inoculants were ‘pure’ ‘declared’ strains with all the isolated identified as the expected and no other strain was present in the product. Nine percent (9 %) of the products in this category contained the expected strain(s) but with ‘undeclared strains’ and 40 % contained none of the expected strains but only undeclared strains.

In category IIA, 29 % of the products were pure, 29 % contained expected strains but also had strains not declared on the label and 42 % did not contain any of the strains indicated on the label (Table 7.2).

Evaluation of Category IIB Arbuscular Mycorrhizal Fungi (AMF) products confirmed the presence of declared, species on the labels, species declared and not detected in products, and non-declared isolates (Faye 2013; Kavoo- Mwangi et al. 2013) (Table 7.3).

Category III products analysis indicated variable organic content (OC), N and P concentration in all products (Aliyu 2012) (Table 7.4). High OC content, were recorded in Zytonic (24 %), Turboseed (14 %), Proplant (12 %), Myconate AS

Table 7.1 Category I products with number of strains as indicated on the label, the number recovered and efficacy of the product

Product name	No. of expected strains in product	No. of strains confirmed	Efficacy of product
Vault ® LVL {*B. japonicum* strain 532C. (5 10^9 CFU mL^{-1}) Liquid and *Bacillus subtilis* strain MBI 600 (Integral) (<1 %)}	2	4	<30 % yield increase. High under greenhouse conditions and low in the field and high biomass, high nodulation, N derived from the atmosphere (Ndfa) and Low nodule occupancy for liquid formulation
Legumefix (*B. japonicum* strain 532C.) Peat formulation	1	1	>30 % yield increase, highest nodulation, biomass, nodule occupancy, N derived from the atmosphere (Ndfa) and yield
Soyflo {*B. japonicum* strain WB74 (2.5 10^2 CFU mL^{-1}) liquid}	1	1	<30 % low yield between 13–20 %, high biomass, high N derived from the atmosphere (Ndfa)
Histick NT – (Peat formulation)	2	4	>30 % high yield, high nodulation, biomass, N derived from the atmosphere (Ndfa), nodule occupancy highest in the long rains
Rizo-Liq Top (Peat formulation)	1	1	>30 % yield increase, high nodulation, biomass and grain yield. Fewer trials under field conditions
Biofix (soybean) (Peat formulation)	1	4	<30 % yield increase, low nodulation, biomass and yield under field conditions

(8 %), and Turbotop (6 %). Nitrogen in the products ranged from 0.01 (Vitazyme and Fulvaboom) to 33 % (Agroleaf high N) while N concentration of Agrolyser and Humaboom was below the levels of detection using the colorimetric methods. Agroleaf high P had the highest P concentration (23 %) and also contained relative high concentration of N (11 %) and K (4 %). Moderate soluble P concentrations were observed in Turbotop (16 %), Turboseed (10 %), and while low concentration was obtained in the Teprosyn (5 %). The K concentration was also found in relatively higher amount in Turbotop (19 %), Agroleaf general (13 %), Turboseed (10 %), Agroleaf high N (4.9 %) and Boost extra (8 %). In addition to the macro nutrients, all the products contained various amounts of micro nutrients. In general, several products contained concentrations of different elements that are far below the levels indicated by the producers or agro-dealers (Aliyu 2012).

Table 7.2 Category II A products with number of strains as indicated on the label and the number recovered and the efficacy of the product

Product name	No. of expected strains in product	No. of strains confirmed	Efficacy of product
Twin-N (*Azorhizobium*, *Azoarcus*, *Azospirillum*)	3	2	Extremely low (5 %) effectiveness on maize, soybean and Tissue culture bananas under the three soil conditions tested
Leguspirflo® (*Azospirillium*)	1	4	Not effective on nodulation of soybean and growth of tissue culture bananas
MycoApply Endo Plus (*Bacillus*)	4	7	Effective on soybean P uptake, increase root biomass, and increases pods. Performs best when applied in combination with Legumfix
Myco Apply Soluble Maxx (*Bacillus*)	15	8	Effective on soybean P uptake, increase root biomass, and increases pods. Performs best when applied in combination with Legumfix
PHC Complete plus (*Bacillus*)	7	7	Not effective on soybean, maize and tissue culture bananas
PHC Colonize AG (*Bacillus* spp.)	6	3	Effective on tissue culture bananas under greenhouse conditions. Increased shoot biomass in Rhodic Ferrasols by 147 % and Vertisols by 334 %
Subtilex (*Bacillus subtilis*)	1	1	Slightly effective on growth of TC bananas under field conditions in Vertisols. Increase of < 10 % not significant. The effect was less under field conditions
PHC Biopak (*Bacilus* spp.)	6	4	Effective on growth of tissue culture bananas under greenhouse conditions. Increased shoot biomass in Rhodic Ferrasols by 113 % and Vertisols by 345 %. The effect was less under field conditions

Greenhouse and Field Evaluation for Efficacy

Eleven Category I products were evaluated under greenhouse conditions. The results indicated that the products were generally similar on their effects in both soils, but differ between two soybean varieties (Thuita et al. 2012). The non-promiscuous (Nyala) variety significantly nodulated with the application of Zim1, Vault, Legumefix, Sojapak, Soyflo, TSBF442 and TSBFmix in descending order, and the highest nodulation in a promiscuous variety was with the application of vault, Soyflo, Histick, Zim1, Sojapak, USDA110, TSBFMix, TSBF442 and Twin N in descending order. The effects of the inoculants on biomass production were minimal. The estimation of nitrogen fixation indicated significant differences

Table 7.3 Category IIB products with number of strains as indicated on the label, the number recovered and efficacy

Product name	No. of expected strains in product	No. of strains confirmed	Efficacy of product
Endorize Standard	*Glomus* spp.	*Glomus* spp.; *Acaulospora tuberculata*	Effective under greenhouse conditions. High nodule fresh wt, shoot dry weight, root dry weight and pod numbers in clay and sandy soil but Increase significant for nodule fresh wt by 33 % and shoot dry weight by 26 % in sandy soil
Endorize Premium -2	4 *Glomus* spp.	3 *Glomus* spp.	Slight increase in P uptake (39 %) and root dry weight (18 %), significantly high nodule fresh wt (54 %), shoot dry weight (63 %) and pod numbers (100 %) in sandy soil
Myco Apply Endo	4 *Glomus* spp.	2 *Glomus* spp. and *Acaulospora tuberculata*	Slight increase under greenhouse conditions of P uptake (7 %), nodule fresh weight (91 %), shoot dry weight (8 %) and pod number (50 %) in clay soil
Myco Apply Soluble Endo	4	1	Inconsistent performance under greenhouse conditions. Increase in P uptake (30), nodule fresh weight (28), shoot dry weight (40.7) and root dry weight (138) and no increase in pod numbers in sand; <5 % increase in P uptake, nodule fresh weight, shoot dry weight, root dry weight, and increase of pod number by 31 % in clay
Myco Apply Endo Plus	8	*Acaulospora tuberculata*	Inconsistent performance. Increase in P uptake (36 %), shoot dry weight (24 %), pod numbers (44 %) in clay and <10 % of all parameters in sand under greenhouse condition
Myco Apply Maxx	9	3	Inconsistent performance. Increase in P uptake (25 %), shoot dry weight (50 %), root dry weight (51 %) in sand and increase in nodule fresh weight (27), root dry weight (42 %) and pod number (31 %)
Myco Apply Soluble Maxx	1	5	Inconsistent in performance. Increase in P uptake (23 %), nodule fresh weight (18), shoo dry weight (21), root dry weight (10.6 %) and pod number (63) in clay and increase in P uptake (25 %) and shoot dry weight (19 %)
Mycor	1	1	Effective on tissue culture banana under greenhouse conditions on shoot biomass (100 %) but not under field conditions. Not effective on soybean. Inconsistent performance with increase in only root dry weight (36 %)

Rhizatech	5	2	Effective on tissue culture banana and increased shoot biomass (131 %) under greenhouse conditions and growth by 28 % under field conditions in Vertisols. Not effective on soybean under greenhouse conditions. Only increase in shoot dry weight (142 %) in sandy soil. Not effective on soybean under field conditions when applied alone. Performs better when combined with Legumefix (15 %). Effective under field conditions on maize when applied with half rate P (25 %)
Vam-Tech	1	1	Inconsistent performance. Slight Increase in P uptake (21 %), nodule fresh weight (15 %), shoot dry weight (<10 %), root dry weight (36 %), pod number (10 %) in sand and increase in P uptake (13 %), nodule fresh weight (23 %) and pod number (38 %) in clay soil
Zander Mycorriza	6	3	Inconsistent performance. Increase in nodule fresh weight (17 %) and root dry weight (38) in sand and root dry weight (16 %) and pod number (25 %) in clay
EcoT (*Trichoderma harzianum*)	1	1	Increase in shoot biomass (81 %) of tissue culture bananas under greenhouse conditions and growth (20 %) under field conditions

Table 7.4 Category III products % minerals indicated on the label, % macronutrients recovered and efficacy of product

Category III products	Nutrient composition and quantity on labels	[a]Nutrient status of product	Efficacy of products
Turbo seed	Zn (P_2O_5 (47 %), K_2O (31 %), Zn (1 %) as Zn EDTA chelate)	P_2O_5 (10 %) and K_2O (10 %)	In soybean, product significantly ($P < 0.05$) increased both P concentration and P uptake in shoot of soybean; t not effective on shoot dry matter yields unless applied with additional Zn. In maize product effective on root growth when applied with additional P
Turbo top	(P_2O_5 (39 %), K_2O (25 %), Mn (0.5 %), Zn (1 %), Cu (0.75 %) and Fulvic powder (the rest))	P_2O_5 (16 %), K_2O 19 %	No effect on maize dry matter yields under greenhouse conditions. The effect is expected at later stages, and it is possible that the growing period in the greenhouse was too short to notice this; significant ($P < 0.05$) positive effects on Zn concentration in the shoot dry matter. Product effective on soybean, with significant positive effects on plant height throughout the growing period, on shoot dry matter yield, pod load and on chlorophyll content and/or nodulation
Agroleaf high N and Agroleaf high P	High K: N (15 %), P_2O_5 (10 %) and K_2O (31 %); High P: N (12 %), P_2O_5 (52 %) and K_2O (5 %); Total: N (20 %), P_2O_5 (20 %) and K2O (20 %) and High N: N (31 %) P_2O_5 (11 %) and K_2O (11 %) All: B (0.03 %), EDTA-chelated Cu (0.07 %), DTPA-chelated Fe (0.07–0.14 %), EDTA-chelated Mn (0.07–0.14 %), Mo (0.001 %), EDTA-chelated Zn (0.07 %), B (0.03 %), EDTA-chelated Cu (0.07 %)	N (33 %); P_2O_5 (3 %) K_2O (4 %)	Agroleaf product, increased ($P = 0.052$) P uptake in stover in Humic nitisols during the long rains and growth although they had no effect on dry matter yields
Teprosyn Zn/P	N (4 %), P_2O_5 (12 %), Zn (19.4 %)	P_2O_5 5 %	An effective product under field experimentation. It increased stover and total biomass yields as well as P concentration in maize grain especially in Humic nitisols

[a]Nutrient status of product: Not all analysis of nutrients on the label was done but only key nutrients such as *N*, *P* and *K*

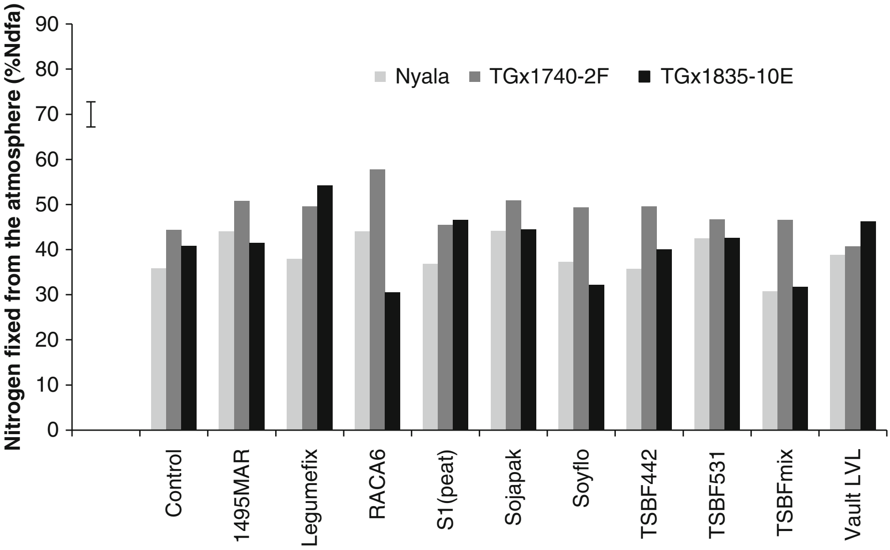

Fig. 7.1 Percentage of N fixed from the atmosphere for Chuka for two soybean varieties during LR2009 cropping season. The error bar represents the standard error of the difference (SED)

($p < 0.05$) due to the inoculants at the Chuka (Humic nitisol) site for the two soybean varieties (Fig. 7.1). Legumefix, TSBF531,1495MAR, S1(peat) and RACA6 fixed significantly higher amounts of nitrogen.

Only the most effective and consistent products were evaluated by collaborating partners IITA and EIAR in addition to their local strains. In the Nigerian savannah zone, similar improvement in productivity was found with three commercial strains (Ncho 2013). An increase in yield of 27 %, 31 % and 33 % of soybean was observed with the inoculants 1495MAR, legumfix and RACA6 respectively.

An economic valuation was conducted for legumefix, which was consistent in its effect across the three countries. Rhizobium inoculation is done by treating the seed, which requires only a minor investment in terms of labor. The main additional cost arises from the purchase of the product. To treat 80 kg of soybean seed (the requirement for planting 1 ha), 320 g of peat-based soybean inoculant is needed, which costs US$ 13.4. As soybean in Kenya on local markets is sold at a unit price of about US$ 0.5 per kg, application of the product needs to increase yields by at least 54 kg ha^{-1} to obtain a benefit-cost ratio (BCR) that exceeds US$ 2 \$$^{-1}$. The average control yield equaled 625 kg ha^{-1}, but varied between 0 and almost 2,600 kg ha^{-1}. The overall average yield increased by 109 kg ha^{-1} due to Rhizobium inoculation, which entails a BCR of US$ 4.1 \$$^{-1}$.

Category II products were variable in their effects and highly dependent on the crop and site conditions. In Nigeria, PHC Biopak (Bacillus product) increased yield of soybean in Kaya by 19 % and of groundnuts in Shanono by 21 % and Rhizatech (mycorrhizal) increased yield by 26 % (Ncho 2013). Out of 10 Category II products

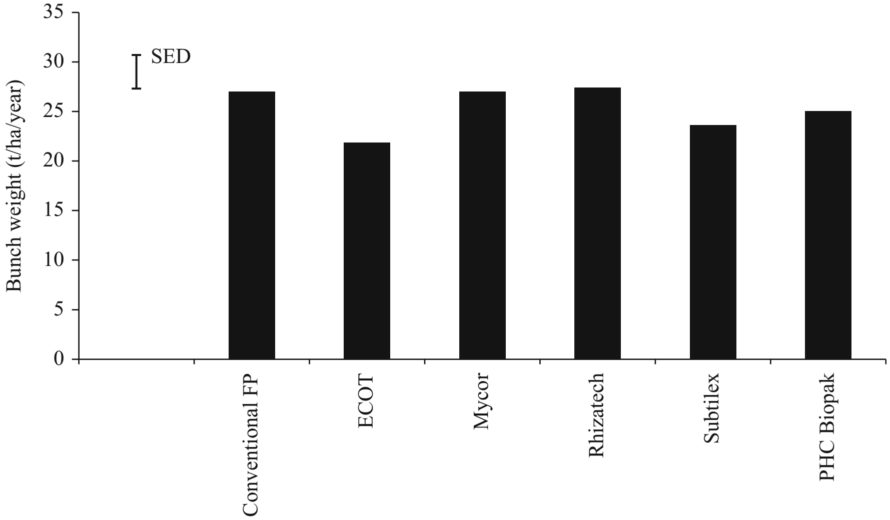

Fig. 7.2 Effect of single products application on the yield of Gros Michel TC banana in Central Kenya

evaluated, only Myco Apply Soluble Maxx showed consistent yield benefits when co-applied with legumefix and supplemented with half recommended DAP rate in soybean (13 kg P ha^{-1}) (Ndung'u-Magiroi 2012). A promising effect for Category II products was more pronounced on tissue cultured bananas grown in Vertisols soil at the nursery stage where growth was increased by PHC Biopak (345 %), PHC Colonize (334 %), Rhizatech (130.86 %), Mycor (100 %), Subtilex (87.83 %) and ECOT (81.06 %) compared to only two products in Rhodic ferrasol with increase observed by inoculation with PHC Biopak (113. 08 %) and PHC Colonize (146.46 %) and no effect in Humic nitisol by the same products. The effects on growth of products were sustained in Vertisols under field conditions particularly by all products with increase of 5–50 % in growth more than the control (Kavoo 2013). The inoculated bananas in Vertisols were not monitored to production stage but evaluation of yield in Humic nitisols showed products to perform just as well as the conventionally managed plant as was observed under nursery conditions (Fig. 7.2).

This displayed the products as an alternative intervention to the widely practiced conventional intervention which uses inorganic fertilizer (DAP), Mocarp, manure and sterilization with firewood. The cost of use of Rhizatech product at US$ 62 per hectare, applied only at hardening and potting stage, realized a net benefit of US$ 5, 265 compared to the cost of conventional practice US$ 135 with a net benefit of US$ 5,115 (Kavoo 2013).

The products were also evaluated *in vitro* for their potential to suppress *Fusarium* spp. populations, the causal agent for *Fusarium* Wilt in Gros Michel.

Table 7.5 Maize grain and stover yields (averaged yields) in Long Rain (LR2010) as affected by the application of alternative P products in three districts of Kenya

	Grain yield (kg/ha)			Stover yield (kg/ha)		
Treatment	Bondo	Bungoma	Meru south	Bondo	Bungoma	Meru south
Control	871	1,942	2,715	1,755	2,819	3,926
HRR	1,329	2,632	3,050	2,520	2,887	3,598
FRR	1,759	2,859	3,312	2,886	3,879	3,849
Seed P coating + HRR	1,624	2,806	2,951	2,571	3,784	4,911
Foliar P + HRR	1,507	2,804	2,959	2,177	3,392	3,947
Soil conditioner + HRR	1,605	2,816	3,292	2,581	3,446	4,324

HRR = Half Recommended Rate (13 kg P ha 1), FRR = Full Recommended Rate (26 kg P ha 1)

Fusarium populations were highest in Central Kenya soils (Humic Nitisol), the region with highest growth of Gros Michel but recently experiencing decline due to *Fusarium* wilt (Kung'u et al. 1998). The products EcoT (*Trichorderma*), Rhizatech (mycorrhizal) and PHC Biopak (*Bacillus* spp.) reduced *Fusarium* population by 68 %, 55 % and 47 % respectively.

The field performance of the most effective Category III products as alternative P formulation on maize in Kenya showed only the seed P coating product Teprosyn, to increase stover and total biomass (grain + stover) yields relative to the treatment with P applied at HRR (Half Recommended Rates) (Munyahali 2012). No effects of the alternative P formulation products were observed on grain yields. Table 7.5 shows the effects of chemical products on maize grain and stover yields under field conditions at three sites in Kenya.

Profitability of the different P formulation products (Nutrient coating of maize seeds [Teprosyn Zn/P, Yara Int.]) was calculated using a partial budgeting. Significant additional net benefit was obtained with the seed P coating and foliar P spray products relative to the treatment with P applied at HRR. However, the benefit cost ratio (BCR) and HRR were favorable only with the seed P coating product. The profitability of the seed P coating product was associated to its low purchasing price and its low labor cost rather than yield increment.

To treat 30 kg of maize seed (the requirement for planting 1 ha), 240 mL of seed coating product is needed, which costs US$ 3.1. As maize in Kenya on local markets is sold at a unit price of about US$ 0.2 per kg, application of the product needs to increase yields by at least 31 kg ha^{-1} to obtain a benefit-cost ratio (BCR) that exceeds US$ 2 \$$^{-1}$. The effectiveness of seed coating with P was demonstrated under greenhouse conditions, but data from field demonstration trials suggested that the effect was only significant in low-P soils, when applied in conjunction with a low dose of P fertilizer (13 kg P ha^{-1}). Single nutrient fertilizer (TSP) which incurs an additional cost of US$ 52 ha^{-1} was used. When Seed P Coating and low TSP fertilizer are applied in combination, increased yield with a BCR of US$ 2.1 \$$^{-1}$ were obtained. If fertilizer use and seed coating are targeted to responsive fields, net benefits can be increased by 38 %, with a BCR of US$ 4.6 \$$^{-1}$.

Conclusion and Recommendations

It is evident from this study that most of the products coming into Africa do not comply with label, have low quality, low concentrations and low viability. Amongst the low quality products, there are still effective products that can benefit small holder farmers. However, they still need to be evaluated in a wide range of agroecologies and soil types in the context of Integrated Soil Fertility Management (ISFM). The study has shown that promising products that can improve yield exist, though extremely few. The few products also vary tremendously in their performance under field conditions, hence the need for evaluation of products under broad range of conditions and the need to come up with site and crop specific recommendations instead of the blanket recommendation made by manufacturers. The general assumption by manufactures is a scenario of homogenous conditions as opposed to the heterogeneous biotic and abiotic conditions that dominate Africa's agricultural landscape. This may be the case when products are evaluated under greenhouse conditions where conditions are homogenous and effects less variable. Biological products composed of microorganisms are derived from specific environment where optimum function is expressed from highly specific to broad range. Specificity or preference for soil and host are rarely taken into consideration by most commercial producers, hence the failure of most products to perform effectively under heterogeneous field conditions. The potential of biological and chemical commercial products as fertilizers and bio-controls is evident but the context of integration and quality of products must be clearly understood and consider the incorporate Integrated Soil Fertility Management (ISFM) practices so as to optimize performance.

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Chapter 8
Enhanced Utilization of Biotechnology Research and Development Innovations in Eastern and Central Africa for Agro-ecological Intensification

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Abstract The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) through its Agrobiodiversity and Biotechnology Programme is enhancing the utilization of biotechnology research and development innovations in Eastern and Central Africa (ECA). We present successes in the application of biotechnology to enhance the productivity of cassava, sweet potato, banana, maize and sorghum in ECA. These products—drought tolerant maize, sorghum resistant to *striga*, as well as the technology for producing and distributing disease free planting materials of cassava, sweet potato and banana to farmers—are central for the agro-ecological intensification of farming systems in the central African highlands.

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Introduction

The livelihoods of about 280 million people in ECA are supported by agriculture on approximately 300 million ha. This agriculture is based on agro-ecological systems that are highly vulnerable to biophysical constraints, such as drought, pests and disease. To address these constraints, ASARECA was developed as a forum for promoting agricultural research and strengthening relations between national agricultural research systems and the international agricultural research system (ASARECA 2006). The strategy recognizes the pivotal role that science and technology can play in addressing constraints to agricultural production as embodied in the Comprehensive Africa Agriculture Development Programme (CAADP) of the African Union. One of its programmes, Agrobiodiversity and Biotechnology, focuses primarily on the utilization of these tools to improve agricultural production (Borlaug and Dowswell 2002; Mugoya and Masiga 2009). Biotechnology offers the promise to improve yield and nutritional quality, as well as human health. Biotechnology is any technique that uses living organisms or substances from such organisms to make or modify a product, to improve plants or animals, or to develop micro-organisms for specific purposes. Agrobiotechnology refers to a range of diverse technologies derived from molecular genetics, plant physiology (especially tissue culture-related techniques), genetic engineering, and the emergent sciences, such as bioinformatics, genomics and proteomics, as applied in crop improvement and management. Here we present the use of biotechnology as an entry point in agricultural intensification as opposed to traditional approaches to enhance the productivity of cassava, sweet potato, banana, maize and sorghum in ECA. These biotechnological tools include the application of tissue culture, conservation biotechnology, genetic engineering and marker-assisted breeding.

Applying Tissue Culture to Improve Farmers' Access to Clean Planting Materials for Cassava, Sweet Potato and Banana

The main constraints to the production of cassava and sweet potato in the ECA sub-region are the high prevalence of pests and diseases, unavailability of suitable varieties, inefficient multiplication and distribution systems, poor market access, and the lack of a conducive policy and regulatory environment. Tissue culture has the potential to produce and rapidly disseminate disease free planting materials in large quantities that are uniform and clean, harvested early, highly marketable, and with uniform yields (Vuylsteke and Swennen 1992; Vuylsteke and Talengera 1998). Tissue culture is an appropriate technique for the delivery of planting materials across countries, as the material can more readily be certified disease free (Van der Linde 2000). In this study, low cost tissue-culture protocols and virus indexing tools for cassava and sweet potato varieties were optimized.

Low cost protocols that have been developed for cassava and sweet potato varieties include those that make use of locally available fertilizers as alternatives to Murashige and Skoog (MS) macro- and micro-nutrients (Ogero et al. 2011, 2012a, b). The produced plantlets are comparable to those produced in full strength MS media and thus support the use of these low cost materials. Other low cost tissue culture options for the production of cassava have been developed to complement and/or aid conventional methods of plant breeding. These protocols make use of low capital investment, cheap labour and low consumption of energy (Ogero et al. 2010).

A DNA-based tool for the detection of viral diseases of sweet potato prevalent in ECA has been developed. This is more effective and sensitive in diagnosing the sweet potato viruses than the currently available protein-based tool and has been recommended for use in quarantine and sweet potato research laboratories (Kim in prep). In addition, a tool, Multiplex RT-PCR, has been optimized that provides a new method for the simultaneous detection of sweet potato viruses and reduces material costs and time compared with several RT-PCR reactions that would be carried out separately for each virus, (Rukarwa and Mukasa 2011). An in-vitro thermotherapy procedure that eliminated sweet potato virus infection was validated (Rukarwa and Mukasa 2011). Up to 77 % of the plants were virus free. A Reverse Transcriptase-Polymerase Chain Reaction (RTPCR) based on a primer pair tool that detects viruses associated with cassava brown streak disease (CBSD) has been improved to simultaneously detect the two viruses (UCBSV and CBSV) and has been validated (Mbanzibwa and Mukasa 2011).

These virus detection tools, the use of planting materials free from pests and disease, and the elimination of viruses will ensure farmers' access to pest and disease free planting materials that will complement traditional approaches to increase the production of cassava, sweet potato and banana for sustainable intensification. The use of tissue culture has other advantages. For example, tissue cultured banana varieties mature early (12–16 months, compared with 2–3 years from the conventional banana), produce bigger bunch weights (30–45 kg) compared with 10–15 kg from conventional material with a higher annual yield/unit of land (40–60 t/ha against 15–20 t/ha previously realized with conventional material).

Other Biotechnology Innovations That Have Been Generated and Utilized in ECA

The programme has facilitated the transfer of banana tissue culture to smallholder farmers, developed a tissue culture certification system, and facilitated the work of the tissue culture business network (TCBN). This was done through partnership with Agrogenetic Technologies Limited (AGT) and AGROBIOTEC LTD. These activities have enabled more than 1,000 farmers to have access to banana plantlets free from pests and diseases, which may increase their production from the current production of 5 t/ha to their potential production of 60 t/ha. A draft certification scheme has been developed for facilitating the exchange of banana tissue culture planting materials (Komayombi et al. 2012). This will provide assurance to buyers/ importers of tissue cultured materials that the materials being purchased are what they are claimed to be by the producer or seller. This will reduce fears that pathogens capable of causing systemic infections on their host plants can be transmitted through vegetative materials from infected mother plants to the young plants. Clean planting materials is a key in increasing the levels of production which is important in addressing food security concerns in the ECA region. In addition, a draft strategic plan for TCBN has been developed and is under review by the stakeholders. This plan will help in sourcing for investments in TCBN to facilitate the implementation of its objectives of promoting tissue culture business development, strengthening partnerships, exchanging business information/scientific data, building capacity, providing policy advice/advocacy and creating technology/product delivery mechanisms (TCBN 2012).

I. Conservation for sustainable availability of cassava and sweet potato germplasm

Cultivated and landraces of cassava and sweet potato have been collected, conserved using conservation biotechnology techniques, and are being characterized. This tool conserves germplasm in the form of test- tube plantlets or artificial seeds, and by cryopreservation (Shang 1984; Xia and Zhu 1987; Dodds 1988; Engelmann 1991; Towill and Jarret 1992; Tang et al. 1994; Blakesley et al. 1997; Guo et al. 1997). This will enhance long-term *ex situ* conservation and the sustainable utilization of cassava and sweet potato plant genetic resources of actual and potential value for the benefit of present and future generations. To enhance the utilization of these materials for breeding and identifying the genes responsible for resistance to CBSD, a genetic linkage map of resistance to CBSD is being developed. This map forms the basis for understanding the genetic basis of tolerance to CBSD in cassava cultivars (Nachinyaya and Kiroba) in order to rapidly and efficiently breed improved varieties (Ferguson in prep).

II. Genetic engineering of maize for drought tolerance

The programme has developed and is making available engineered maize genotypes tolerant to drought and adapted to ECA. This was done using genetic engineering approaches of gene up-regulation, under-regulation (silencing), and drought inducible expression of candidate genes. To date, 16 maize genotypes have successfully been transformed with 11 genes conferring drought tolerance; *Annexin p35, Annat1, NHX1, XVPRX2, XVSAP1, XVG6, IPT, CBF 1, PMI, amiRNA and Bar genes*. The maize genotypes developed using these genetic engineering technologies are being advanced and evaluated in the glasshouse at Kenyatta University in preparation for drought stress experiments and field trials. This approach has generated drought tolerant maize much faster than traditional approaches. These maize lines will form a major component in agricultural intensification.

Fighting *Striga* with Resistant Genes Deployed to Boost Sorghum Productivity

The programme utilized modern biotechnology tools to identify and map quantitative trait loci (QTLs) associated with resistance to *striga* and assigned them to their specific chromosomal locations by tagging them with tightly linked markers This will improve the precision with which these QTLs are being exploited through map-based cloning for resistance genes and in breeding the varieties that farmers prefer or the market demands *Striga* resistance genes were introgressed from the donor parent N13 into farmer preferred sorghum backgrounds Tabat, Wad Ahmed, and AG8 from Sudan; Hugurty from Eritrea; Ochuti from Kenya; and IS8193 from Rwanda, using marker assisted selection (MAS). Fifty- six superior *striga* resistant BC3 lines were generated (Masiga et al. in prep). Twenty-two lines are currently being evaluated in Sudan, Eritrea, Kenya, Uganda, Tanzania and Rwanda for agronomic performance and *striga* resistance with the aim of releasing them for commercial use in ECA. These resistant lines are important entry points leading towards agricultural intensification.

Lessons Learnt and Consequences for Agro-ecological Intensification of Agriculture

Cassava, sweet potato, maize, banana and sorghum are the main farming enterprises and form a major component of central African farming systems. Farming involving these enterprises is practised by smallholder subsistence farmers in ECA who are experiencing low production due to both abiotic and biotic constraints. Among the key constraints is drought for maize; pests and diseases for banana, sweet potato and cassava; and *striga* on sorghum.. We have learnt that by supplying farmers with vegetatively propagated crops that are free from diseases we can significantly improve the production of such crops. These disease free planting materials can be produced using low cost tissue culture technologies. Private sector laboratories can distribute the clean planting materials to the farmers. By developing sorghum resistant to *striga* using MAS, we have generated a key variety that can be used in the agricultural intensification system as *striga* is the main constraint to sorghum production in ECA. For agro-ecological systems where drought is the main constraint to maize production, transformation technologies have been used to develop maize resistant to drought. If farmers have access to this, it will form a major component in agro-ecological intensification of agriculture. We conclude that biotechnology has made a significant contribution to the intensification of farming systems. The region however needs to speed up the process of facilitating the formulation and implementation of the biosafety regulations.

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Chapter 9

Investing in Land and Water Management Practices in the Ethiopian Highlands: Short- or Long-Term Benefits?

Yihenew G. Selassie and Tilahun Amede

Abstract The Ethiopian highlands are characterized by land degradation, erosion and low productivity, while they serve as the water towers of the region. It is estimated that over 1.9 billion tons of soil are lost from the highlands of Ethiopia each year, with the soil loss ranging from 5 to 300 t/ha/year, depending on the land use. This is, on average, equivalent to a 2.5 cm depth of soil per hectare. Land degradation has been costing the country at least 2–3 % of the agricultural GDP. The direct cost of land degradation is not only nutrient loss but also reduction in crop and livestock productivity, increased incidence of forest removal and decreased farmland for the ever-increasing population. Moreover, the upstream land degradation is also costing downstream countries (Sudan and Egypt) from about US$280 to 480 million to clear sediments annually. There are tremendous efforts by the Ethiopian Government and its partners to minimize the negative effects of land degradation and improve the productivity of these lands. Case studies on the potential benefits of soil and water management indicate that organic matter content and crop yields increased up to three times, while nitrogen content has doubled in a 10-year time span. The benefits were much higher when the physical interventions were applied with vegetative measures (e.g., tree lucerne, vetiver, Napier grass). Interventions have also increased the water budget of the landscape, improved crop water productivity, and reduced nutrient movement. However, the adoption by farmers of Sustainable Land Management interventions

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was possible only when incentive mechanisms, including participatory planning processes, are used, collective action of communities and local authorities is created, short-term benefits addressing food and feed security are introduced, and a process of linking natural resource management with market opportunities is implemented. This paper highlights best-bets and innovations learned in land and water management research and development in Ethiopia over the last four decades, primarily from the experiences of the Soil Conservation Research Project (SCRP), the African Highlands Initiative program (AHI) and the ongoing, government-owned Sustainable Land Management program (SLM).

Introduction

The principal environmental problem in the Eastern African highlands is land degradation, manifested mainly in the form of soil erosion, gully formation, soil fertility loss, water scarcity, and reductions in crop yield. The problem of land degradation is pronounced in the Ethiopian highlands. Land degradation can be described as a reduction of the resource potential or a combination of processes acting on the land, such as erosion by water and wind, bringing about a deterioration of the physical, chemical, biological and economic properties of the soil (Maitima and Olson 2001). It reduces crop and livestock productivity through depleting soil, land and water resources upon which the majority of the population depends for their livelihoods. The excessive dependence of the Ethiopian rural population on natural resources, particularly land, as a means of livelihood is an underlying cause of the degradation of land and other natural resources (EPA 1998).

As a response to the recurrent food insecurity and drought, the Ethiopian Government has been hugely investing on land and water management through constructing terraces, soil bunds, water catchment pits, and also enclosures for protecting the landscape from a direct contact with livestock. Although the short-term goals are to reduce soil erosion and landslides, there has been also a longer-term implication in the aspects of improving soil-water status, improving soil fertility and crop yield, recharging ground water, and increasing the water yield for small-scale irrigation in downstream communities. These efforts have continued in an organized manner through the Sustainable Land Management (SLM) programmes of the Ministry of Agriculture and the Safety-Net programme. This paper highlights best-bets and innovations learned in land and water management research and development in Ethiopia over the last four decades, primarily from the experiences of the Soil Conservation Research Project (SCRP), the African Highlands Initiative program (AHI) and the ongoing, government-owned Sustainable Land Management program (SLM).

Status of Soil Loss and Land Degradation in Ethiopia

According to Constable (1985), soil erosion is considered to be a major agricultural problem in Ethiopia, particularly in the highlands (more than 1,500 m.a.s.l), which constitute 43 % of the total area of the country. Because of population pressure, all possible arable lands including steep slopes (up to 60 %) have been cultivated. The Ethiopian Highland Reclamation Study (EHRS) estimated that the average annual soil loss from arable lands was 100 t/ha/year and the average productivity loss on cropland was 1.8 %/year (Constable 1985).

It is estimated that over 1,900 million t/year of soil are lost from the Ethiopian highlands (EHRS 1984). About half of the highland areas (about 27 million ha) is significantly eroded and over one-fourth (14 million ha) are seriously eroded. Moreover, 2 million ha are permanently degraded so that the land is no longer able to support cultivation (EHRS 1984). An estimated average loss of 20 t/ha/year is common though it could be higher on steep slopes (Mulatie 2009). Measured values range from 0 to 300 t ha^{-1} year^{-1} on specific plots (Hurni 1985). Tamrie (1995) also estimated that the amount of soil loss from erosion ranges from 1,248 to 23,400 million t ha^{-1} year^{-1} from 78 million ha of pasture, rangelands and cultivated fields in Ethiopia.

In the Amhara region, the soil loss due to water erosion is estimated to be 58 % of the total soil loss in the country (Tesfahun and Osman 2003). This has already resulted in a reduction of agricultural productivity of 2–3 %/year, taking out of production a considerable area of arable land. The situation is becoming catastrophic because increasingly marginal lands are being cultivated, even on very steep slopes (Tesfahun and Osman 2003).

The Woody Biomass Inventory and Strategic Planning Project (WBISPP 2000) indicated that 82 % of the Amhara Region has a soil loss rate of less than 12.5 t ha^{-1} year^{-1} while 18 % suffers a soil loss of 12.5–200 t ha^{-1} year^{-1}. Using a conventional soil loss measuring method, Berhe (1996) found a soil loss ranging from 18 to 214.8 t ha^{-1} year^{-1} from the six soil conservation sites in the research project (SCRP). Sites located in the Amhara National Regional State (May bar, Andit Tid and Anjene) registered the highest soil loss.

The upstream soil erosions are not costing only Ethiopia but also the downstream countries such as Sudan and Egypt. About 90 % of the sediment entering Sudan originates from the Ethiopian highlands (Ahmed 2007), destroying dams and agricultural fields. The sediment load from the Blue Nile at El Diem is 140 million t/year and at Aswan it is 160 million t year^{-1}. For this reason, Sennar dam in 61 years lost 71 % (660 million m^3) of its original reservoir capacity. The cost of restoring lost storage in Sudan by conventional dredging without the additional cost of providing disposal areas and containment facilities is reported to be US\$2–3/m^3 (Mohamood 1987). Since 1 m^3 soil weighs about 1 tonne, costs can reach up to US\$280–420 million/year for Sudan and US\$320–480 million/year for Egypt. These losses of productive topsoil are irreversible for it takes many years to generate a productive arable layer.

Methods and Data Sources

As indicated above this synthesis paper is highlighting major lessons learned from within Ethiopia for the last four decades, particularly from three big and long-term natural resources management initiatives, which have been partly supported by external development partners.

1. The Soil Conservation Research Project (SCRP) was a long-term Swiss funded project, jointly implemented by the Ministry of Agriculture and the University of Bern, Switzerland to conduct soil conservation and management research from 1981 to 1996. Its main objective was to minimize land degradation and improve food security through reducing soil erosion in Ethiopian highlands (Hurni 1988).
2. The African Highlands Initiative (AHI) was a multi-institutional, eco-regional initiative of the International Agricultural Research Institutes (CGIAR centers) and the National Agricultural Research Institutes of East and Central African countries, established in 1992. AHI has been developing and pilot testing an integrated natural resources management approach in selected highland areas of Ethiopia, Kenya, Tanzania, Uganda and Madagascar and institutionalizing its use in key partner organizations. It has been operating in Ethiopia since 1995 and developed high level outputs and outcomes in natural resources management (German et al. 2012).
3. During the end of the 1980s the Ministry of Agriculture of Ethiopia and the World Food Programme (WFP) designed a disaster mitigation strategy to consolidate the soil and water conservation and afforestation works in the country on a larger watershed basis. A land rehabilitation project marked the beginning of large-scale soil and water conservation and land rehabilitation programmes linked to watershed development in the country (Amede et al. 2007). The project had a major Food for Work (FFW) component. By the end of 1992, WFP and the Ministry of Agriculture adopted the Local Level Participatory Planning Approach, with sets of guidelines produced to facilitate the planning process on the ground (Carruchi 2005). The project has slowly evolved to be a national resources management since then, currently operating in more than 300 districts in the country.

Factors Causing Land Degradation and Water Scarcity in the Ethiopian Highlands

The region has been under subsistence agriculture for more than a century, experiencing inappropriate land use systems, nutrient mining, and soil erosion for centuries. With the expansion of agriculture to hillsides and the degradation of wetlands, erosion was also expanding from Gonder and Wollo, traditionally areas with a low potential, to West and East Gojam, Awi, and the Lake Tana watershed with a high potential. These areas used to be the bread-baskets of the country, but with very fragile and landscapes prone to erosion.

While soil erosion is a major trigger of land degradation and the decline in soil fertility in the Ethiopian highlands, nutrient mining through crop removal and the limited application and availability of appropriate types of chemical fertilizers are equally important. The application of fertilizers in the region is very much limited for various reasons: (1) Farmers rarely see the returns from the application of fertilizers because nutrients and seeds are washed away by water erosion; (2) The high cost of chemical fertilizers forces farmer to apply them in small amounts which rarely satisfy the basic demands of soil functions (e.g., P fixation) let alone the crops; (3) There is very strong competition for organic fertilizers among soil fertility, livestock feed and household energy, and (4) Nutrient availability and yield are commonly affected by a deficit in other key nutrients (particularly micronutrients) and soil water, which are the most lacking. Moreover, reversing land degradation and improving soil fertility demands an integrated landscape management, which would positively influence the general agricultural productivity and ecosystem services.

Benefits from Soil and Water Management Efforts

Despite strong policy and financial support to promote water harvesting in Ethiopia, the outcomes of the initiative country-wide were largely disappointing. This was especially true for water harvesting structures lined with concrete which were costly and difficult to maintain. However, there are multiple cases where the well-planned and participatory development of water harvesting structures brought about apparent benefits, particularly in the SLM target districts (e.g. Alaba). Farmers produced high-value vegetables and fruits in their home gardens during the dry seasons; the travelling distance of livestock was reduced; the structures were used as sources of supplementary irrigation during dry spells and enabled farmers to get additional income throughout the year. This has been particularly true in drier environments where rainfall is short and unreliable and in pastoral and agropastoral systems where water harvesting has been traditionally the most important source of water for livestock keeping and household uses. One of the areas to be most successful SLM projects in water harvesting was the Kalu District in the Amhara Regional State. Once an area devastated by the drought and famine of the 1980s it is now becoming one of the exemplary areas, whereby farmers have reversed the situation and have a productive landscape by linking water harvesting with the production of high-value crops. Each household is now generating up to 45,000 birr/season (equivalent to US$2,650) from *Chat* and fruits watered by water harvesting ponds. Each household has developed at least three ponds lined with

Table 9.1 Effect of SWC measures on soil properties and yield of barley

Treatments	Organic matter (g/kg)	Total nitrogen (g/kg)	Infiltration rate (cm/h)	Grain yield (kg/ha)
Control (Non-conserved land)	0.16^{d}	0.013^{c}	0.24^{b}	561.0^{d}
6-years old soil bund + tree lucerne	0.25^{c}	0.017^{bc}	0.28^{b}	1284.0^{c}
9-years old soil bund + tree lucerne	0.50^{a}	0.028^{a}	0.73^{a}	1879.0^{a}
9-years old soil bund + vetiver	0.33^{b}	0.022^{b}	0.82^{a}	1188.0^{c}
9-years old soil bund	0.55^{a}	0.028^{a}	0.88^{a}	$1,713.0^{b}$
CV (%)	14.00	17.48	44.80	7.8
$SE_{\bar{x}}$	0.25	0.019	0.11	51.8

$SE_{\bar{x}}$ = Standard Error of means

geo-membranes (personal observation). They have moved from being recipients of food aid to market-oriented farmers with easy access to cash and interventions. The community has now been requested to supply planting materials for apple for the whole Amhara region, with one seedling costing 40 birr. Most studies found that rainwater harvesting ponds built close to homesteads and used for irrigating gardens are more effective than those built in more distant fields for the supplementary irrigation of staple crops (which had initially been the intention of government).

Amede et al. (2011) reported a yield benefit of up to 500 % in fields planted with potato in Zai pits, which are used to capture the run-off along with the application of organic resources. Productivity of potato and beans has also significantly increased due to the combined effects of soil water with nutrient management. Water harvesting is also an important intervention for livestock systems. Land degradation by livestock is commonly associated with a lack of watering points, as livestock have to travel long distances in search of water. In the dry season, when the shortage was severe, animals had to walk 12 km/day to have access to water, and this reduced milk and meat yield by about 50 %.

Tadele et al. (2011) conducted an experiment at Absela Kebele, Banja Shikudad District, Amhara National Regional State. They compared different bio-physical conservations measures and measured organic matter, total nitrogen, and the infiltration rate and grain yield of barley. Results of the experiment indicated that there was highly significant ($p \leq 0.05$) difference in organic matter, total nitrogen, infiltration rate and yield contents (Table 9.1).

Land degradation has been costing the country hugely; at least 2–3 % of the agricultural GDP, whereby the cumulative costs of land degradation on the countries agriculture based economy is significant (World Bank 2007). The direct cost of land degradation is beyond nutrient loss through topsoil removal. It reduces crop and livestock productivity, increase the incidence of forest removal in search for additional farmland, and decreases the availability of productive land for the ever-increasing population.

Incentives for the Successful Implementation of Soil and Water Management

One of the major disincentives for adoption was the top-down and authoritarian approaches that had been followed by development and government institutions (German et al. 2012). People were forced to do things that they were not informed about, and there was no discussion with them about the costs, affordability, social implications and short- and long-term benefits. The most successful soil water management practices are those, which are commonly implemented under a bigger watershed management designed and conducted in close engagement with local communities. The sustainable benefits of these practices were also apparent when the soil water conserving (SWC) structures are combined with biological interventions, which brought about immediate benefits for farmers in the form of food, fuel, feed and income. Figure 9.1 illustrates how degraded landscapes were converted to productive sites for animal feed through SLM projects.

The approach emanated from the project called 'MERET', supported by the World Food Programme and adopted nationwide through the Sustainable Land Management (SLM) programme. It could be described as follows (Amede et al. 2007, 2011):

1. **Creating local consensus between communities and authorities**

A multidisciplinary district-level watershed management team, composed of experts of the District Office of Agriculture and development partners, was established to select priority watersheds, support the local-level planning process, and provide technical backstopping during the implementation stage. The selected sub-watersheds and planned activities were presented to the district council for

Fig. 9.1 Transformation of degraded lands into productive feed and wood source (Source: GiZ, Debre Tabor Coordination office (personal communication))

approval. This was meant to get the buy-in and support from the local authorities. This was followed by reconnaissance visits from the district-level team to the selected watersheds. They held talks with *kebele*-level authorities (lowest administrative unit) and community leaders to introduce watershed management principles, the potential benefits and consequences, and explained what was likely to be done in the selected watershed to get agreement on the next steps. Based on the information collected, the community-level base map was developed, describing the current status and presenting a development map that illustrated the intervention sites in relation to the desired land use types. Communities discussed and approved these maps as instruments to guide future intervention. The planning team, which included community representatives, identified and prioritized innovations for the watershed.

Stakeholders at all levels implemented the plan. Regional and district officials mobilized resources, organized training and other support, such as focused study tours to facilitate the successful implementation of the plan. At the local-level, community leaders mobilized collective action and ensured equitable responsibility and benefit sharing. They jointly investigated how the plan is being implemented, whether changes were needed and the expected results were still realistic, and if new alternatives had become available. These reflections are integrated while the next cycle is being planned. Going through this process created opportunities for institutional and individual learning. The experience was used to refine the processes and apply them when initiating new projects in other districts.

2. **Aligning long-term plans with short-term benefits**

The success of the NRM in the Ethiopian highlands was made possible thanks to three short- term incentive mechanisms:

(i) The use of Food for Work (FFW) for implementing SLM practices. The shift from the free delivery of aid to development-oriented tasks created opportunities for a substantial amount of labour to be mobilized for conservation work every year. This strategy has evolved towards a safety net programme, a policy which is trying to minimize the asset losses of resource-poor farmers through climatic and market shocks by providing regular support for SLM (usually for 5 years) until they graduate out of poverty.

(ii) Most of the SWC structures used to be destroyed by free livestock movement. Trees planted were not surviving for a season. Managing free grazing through the establishment of local bylaws was a key incentive for adopting land management practices.

(iii) Equitable responsibility and benefit sharing arrangements were adopted by the communities. These policies were mediated by existing institutions and norms. Communities also developed new rules and regulations to ensure the successful implementation of activities agreed upon, i.e., incremental sanctions when people do not show up on collective working days in the watersheds or when grazing occurs in the exclusion zone; failure to abide by commonly agreed terms can result in social exclusion. The local authorities have now recognized and enforced the local rules to manage free raiders.

(iv) Linking NRM to market opportunities: The most successful experiences in Ethiopia in terms of land and water management are coming from Tigrai and Wollo. Integrating beehives into watershed management attracted the attention of farmers and encouraged them to grow trees and protect the watersheds. Investment in soil and water conservation is yielding more water from springs and shallow wells which has been used to grow fruits, vegetables, fodder grasses, and other high- value products for the local market.

(v) Exchange visits to successful watersheds within the country: Cross-watershed farmer-to-farmer visits were instrumental in successful watershed management. Those who visited successful sites became champions of NRM in their localities. The local experts also learned fast from ongoing and proven experiences.

Conclusions and Recommendations

Land and water management is a complex socio-ecological management, whereby appropriate technologies and practices are employed through participatory planning and facilitation at the community and higher levels. Moreover, while land and water management is a long-term investment, farmers are keen to invest only in enterprises that would have immediate economic returns. There is a need for strategic investment in minimizing land degradation through improved landscape management, rainwater management, and the application of critical nutrients into the farming systems to achieve short- and long-term benefits. There is a need to capitalize on the good watershed management practices, where local institutions are taking charge of their landscapes. For this to happen, there is a need to strengthen market linkages and build local capacity at various scales.

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Chapter 10

Yield Responses of Cowpea (*Vigna unguiculata*) Varieties to Phosphorus Fertilizer Application Across a Soil Fertility Gradient in Western Kenyan Highlands

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Abstract Declining soil fertility resulting from continuous cultivation, confounded with inadequate fertilizer use and the growing of poor local cowpea (*Vigna unguiculata*) seed varieties has led to decreased yields in smallholder farms in the highlands of western Kenya. However, applying phosphorus (P) and planting improved varieties could result in increased yields of biomass and grain. This study screened the performance of local and improved cowpea varieties under different application rates of P – fertilizer (Triple Super Phosphate). The study was conducted in Nandi South District and considered four sites where the soil fertility was classified as low (Kapkerer), medium-low (Kiptaruswo), medium-high (Bonjoge) and high (Koibem). Field experiments were conducted in 2009 during the long rains (LR) and short rains (SR) seasons. The experiments were factorially arranged and laid out in a randomized complete block design (RCBD) with three replications at all the sites. Phosphorus was applied at three levels: 0, 15, and 30 kg P/ha. During LR 2009, three local cowpea varieties were tested; Enzegu, Khaki and Ilanda. During SR 2009, six cowpea varieties were tested; one local check (Khaki) and five improved varieties, ICV1, 1CV12, CB46, IT92K-282-2 and IT83D-442. The resultant data on dry matter (DM) and grain yields were collected and subjected to statistical analysis

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to determine differences in the means. Across varieties, during LR and SR, application of P resulted in insignificant ($p < 0.05$) increases in mean cowpea DM within sites. During SR, application of P resulted in insignificant ($p < 0.05$) increases in the yield of cowpea grain across varieties. Within sites, however, the 15 kg P/ha rate resulted in a 33 % increase in grain yield relative to the control in Bonjoge and to a 62 % increase in Koibem. The results of this study show that, despite the high fertility status of the Bonjoge and Koibem sites, they still require the application of P – fertilizer for increased production of cowpea grain. Kapkerer and Bonjoge sites had the highest DM and grain yields. Across sites, the most suitable cowpea varieties for the production of DM are Enzegu during LR and Khaki and ICV 6 during SR. The most suitable cowpea varieties for the production of grain are CB 46 in Bonjoge and ICV 12 in Koibem. Although cowpea productivity is influenced by the soil's fertility status, the application of P is essential for enhancing DM accumulation and grain yield production.

Keywords Western Kenya highlands • Fertility clusters • Cowpea • Dry matter yield • Grain yield

Introduction

In an effort to feed the ever – increasing population in Nandi South District, forests have been converted to agricultural lands to provide space for farming. The time taken to convert these forest lands has resulted in soil fertility clusters with differential nutrient levels and climatic variability (Kimetu et al. 2008). These agricultural lands are subjected to intensified and continuous cultivation with minimum nutrient replenishment (Okalebo et al. 1997) resulting in the gradual depletion of soil nutrients, hence in declining crop yields. Although farmers use fertilizer in certain regions of Nandi South District, the amounts used may be limited for a variety of reasons, such as costs and availability (Vanlauwe and Giller, 2006). Unpredictable climatic changes, variability in soil fertility, inadequate fertilizer use and the growing of poor local legume seed varieties that are susceptible to major pests and diseases, have led to grestly decreased yields in smallholder farms in the District.

Cowpea is a hardy crop that may offer an alternative source of food and income. It is versatile, in that it can be grown across wide range of soils and in areas of marginal rainfall amounts (Bagayoko et al. 2000). In addition, cowpea cultivation can be an important option for rebuilding soil fertility through the biological nitrogen fixation (BNF) process. Improved varieties are highly vigorous and resistant to major diseases and pests (Singh et al. 1985). External addition of P at recommended rates may result in increased yields of leaves and grain of these varieties (FURP 1994). This is because nutrient P plays fundamental roles in crop production by providing energy, enhancing the BNF process, flowering, seed formation and root establishment and development (Vance 2001). Since the consumption of cowpea leaves and grain is essential for addressing iron deficiency (www.plantphysiol.org), increased yields will not only provide more food and income to the majority of families in western Kenya but also improve their human health. Against this background, local and improved cowpea varieties were screened to investigate their dry matter (DM leaves) and grain yield response under different P – fertilizer rates at sites with different levels of soil fertility in Nandi South District, western Kenya.

Materials and Methods

The experiments were conducted in 2009 during the long rains (LR) and short rains (SR) at four sites (Kapkerer, Kiptaruswo, Bonjoge and Koibem) with different levels of soil fertility status and agro-ecological conditions (Table 10.1). Classification of the sites into the four soil fertility clusters (low, medium-low, medium-high and high) was based on the time that had elapsed from the conversion of the land from forest to farmland. Kapkerer was the oldest of the sites to be settled by the inhabitants of the region and had been under cultivation for over 80 years. This site was classified as having low fertility. On the other hand, Koibem represented an area more recently excised from forest and settled for less than 30 years; this site was considered to have high soil fertility. Kiptaruswo was considered medium-low in fertility and at Bonjoge, it was medium-high. The soil fertility gradient classification was confirmed by chemical tests (Table 10.2).

The experimental treatments were laid out in a randomized complete block design (RCBD) with 3 × 3 (LR) and 3 × 6 (SR) factorial arrangements of treatments, replicated three times. During the LR and SR experiments, P sourced from TSP fertilizer was applied at 0, 15, and 30 kg P/ha. Cowpea varieties Enzegu, Khaki and Ilanda were tested during the LR experiment; ICV 6, ICV 12, CB 46, IT 90 K-284-2 and IT 83D-442 (improved) and Khaki (local check), were tested during the SR experiment. During LR, the cowpea varieties studied were farmers' landraces that

Table 10.1 Geographical and soil information of the study sites in Nandi South District, western Kenya

Location	Kapkerer	Kiptaruswo	Bonjoge	Koibem
Coordinates	N 00° 00′ 319″ E 34° 48′14.6″	N 00° 02′ 28.1″ E 34° 56′ 35.9″	N 00° 06′ 52.2″ E 34° 54′ 42.6″	N 00° 09′ 28.2″ E 34° 54′ 31.9″
Soil fertility clusters	Low	Medium Low	Medium high	High
Altitude (masl)	1,530	1,582	1,674	1,770
Rainfall (mm/year)	1,600	1,700	1,800	2,000
Annual temperature (°C)	21	20	18.5	18
FAO/UNESCO Soil class	Ferralo-orthic Acrisols	Ferralo-orthic Acrisols	Ferralo-chromic Acrisols	Humic Acrisols
Conversion time from forest to farmland (years)	80–105	60–80	30–60	5–30

Source: Jaeztold and Schmidt (1983)
NB: *masl* metres above sea level

Table 10.2 Soil chemical and physical characteristics of surface soils (0–20 cm) taken at study sites before 2009 LR experiment

	Experimental sites			
Soil parameters	Kapkerer	Kiptaruswo	Bonjoge	Koibem
pH_{water} (1:2.5 H_2O)	5.31	5.54	5.81	6.12
Organic carbon (mgkg^{-1} × 10^4)	1.44	1.87	3.53	3.91
Nitrogen (mgkg^{-1} × 10^4)	0.16	0.26	0.31	0.38
Olsen P (mgkg^{-1})	7.59	8.12	9.25	9.38
C: N	9.00	7.19	11.39	10.29
Sand (mgkg^{-1} × 10^4)	67	73	71	67
Silt (mgkg^{-1} × 10^4)	8	18	22	24
Clay (mgkg^{-1} × 10^4)	25	9	7	9
Soil type	Sandy clay loam	Sandy loam	Sandy loam	Sandy loam

performed better under high rainfall amounts. During the SR, improved cowpea varieties studied could only perform optimally only under minimal rainfall amounts. Khaki, a variety that could withstand both long and short rains, was the local check.

Site Characterization

Initial soil characterization was done by taking 15 samples randomly at each site. With use of augurs, (5 cores/site) were taken to a depth of 0–20 cm. The soil was thoroughly mixed to make a composite from which a sample, weighing about 500 g, was taken to the laboratory for analysis. The soil was air – dried and lumps were crushed gently to separate the soil from foreign matter. The soil was later sieved (<2 mm) and analyzed for pH (determined with water 2.5:1 H_2O), extractable P (determined calorimetrically, Murphy and Riley 1962), particle size (hydrometer method) and sieved through (<0.75 mm) for organic carbon and total N analysis (by weight of air-dried soil, Nelson and Sommers 1982) following the procedures described in Okalebo et al. (2002).

Experimental Establishment and Management

At sowing, cowpea seeds were spaced at 45 cm by 15 cm. Routine agronomic management practices were followed throughout the growing period. Weeding was done three times during the LR and SR experiments. Trenches were dug around the borders of the experimental area to control fertilizer wash into the experimental plots. Dimethoate 40 EC (Danadim ®) was sprayed to control aphids (*Aphis craccivora*) during the SR experiment. Agronomic data collected from the experiment included final above – ground DM and grain yield. At physiological maturity, the fresh total weight of cowpea above – ground biomass was taken, including pods, by cutting the plant's base nearest to the ground. A sample of well – mixed fresh biomass was placed in paper bags, weighed fresh and later dried in an oven (65 °C) to constant weight. The DM was then weighed and recorded; the weight was calculated from the sample weights. Cowpea pods at physiological maturity were threshed and grains were collected. Grain samples were oven – dried at 65 °C to a constant weight.

Data were analyzed using SAS Statistical software; release 8.2 SAS Institute Inc., (2001). Least Significant Difference (LSD) test was used to separate means of parameters significant at 95 % confidence level. The models employed in the analysis were:

$$\mathit{Within\ Site\ analysis}\colon Y_{ij} = \mu + A_i + B_j + AB_{ij} + \sum\nolimits_{ij}$$

$$\mathit{Across\ Site\ analysis}\colon Y_{ijk} = \mu + A_i + B_j + AB_{ij} + S_k + SA_{ik} + SB_{jk} + SAB_{ijk} + \sum\nolimits_{ijk}$$

where;

Y: Plot observations, μ: Overall mean of plot observations, A_i: Effect due to P fertilizer, B_j: Effect due to cowpea varieties, AB_{ij}: Interaction between P fertilizer and cowpea varieties, S_k: Effect of site, SA_{ik}: Interaction between site and P fertilizer, SB_{jk}: Interaction between site and cowpea varieties, SAB_{ijk}: Interaction between site, P fertilizer and cowpea varieties, $\sum_{ijkl}$: Overall experimental error.

Results

Initial Soil Chemical and Physical Characterization of Study Sites in Nandi South District

Initial soil characterization confirmed a clear decline in soil nutrient levels, i.e., soil organic carbon SOC, total N and extractable P, across the soil fertility gradient (Table 10.2) and was in the order; Koibem (high fertility site: HFS), Bonjoge (medium – high site: MHFS), Kiptaruswo (medium – low site: MLFS) to Kapkerer (low fertility site: LFS). The soils were acidic in all sites, i.e., with a soil pH value less than 7. The Kapkerer site out of the four sites (pH value 5.13) had the most. The soils at all sites showed limiting levels of P (<10 ppm extractable P). According to Woomer et al. (2003), acidic soils in western Kenya have strong evidence of widespread deficiencies in N and P resulting from P fixation. Koibem site (HFS) and Bonjoge (MHFS) had values of SOC and N above the critical threshold levels considered adequate for crop production (Okalebo et al. 2002). However, the

Kapkerer site had the lowest values of SOC and total N; hence it was classified as LFS. The soil type in all sites was sandy loam, except at Kapkerer where it was sandy clay loam. The highest percentage clay fraction was observed in Kapkerer (25 %) and the lowest at Koibem (9 %).

Within and Across Site Effect of P – Fertilizer Application on Cowpea DM Yield During LR 2009 Experiment

Generally, a low final DM yield was observed at all sites due to the heavy rains and hailstones experienced during the LR season. The application of P did not significantly ($p < 0.05$) influence the mean DM yield at all sites (Table 10.3). However, in Bonjoge (MHFS), the mean DM yield increased by 31 % as a result of the application of P at 15 kg P/ha and by 178 % after 30 kg P/ha. Across P rates, varietal differences significantly ($p < 0.05$) influenced the mean DM yield at all studied sites (Table 10.3). In Kapkerer (LFS), Kiptaruswo (MLFS) and Bonjoge (MHFS), Ilanda variety gave significantly ($p < 0.05$) the highest mean DM yield (Table 10.3).

In Koibem (HFS), however, Enzegu variety gave the highest mean DM yield. Khaki variety produced the lowest DM yield across at all sites (Table 10.3).

The effect of site significantly ($p < 0.05$) influenced the grand mean DM yields across varieties (Table 10.3). The highest significant ($p < 0.05$) mean DM yield of 927 kg/ha observed in Kapkerer (LFS), was 200 % greater than that observed in Koibem (HFS), 500 % more in Kiptaruswo (MLFS) and 600 % more than in Bonjoge (MHFS).

Within and Across Site Effects of P – Fertilizer Application on Cowpea DM Yield During SR 2009 Experiment

The application of P did not significantly ($p < 0.05$) influence the mean DM yield in all sites studied (Table 10.4). In Kapkerer (LFS) and Kiptaruswo (MLFS), the mean DM yield was higher at the no P rate than at 30 kg P/ha rate. In Bonjoge (MHFS), the 15 kg P/ha rate showed the highest mean DM yield. In Koibem (HFS), P application at 30 kg P/ha rate increased mean DM yield by 10 % compared with no P and by 15 % compared with 15 kg P/ha (Table 10.4).

Varietal differences significantly ($p < 0.05$) influenced the mean DM yield in Kapkerer (LFS) and Koibem (HFS) (Table 10.4), but not in Kiptaruswo (MLFS) and Bonjoge (MHFS). Khaki gave the significantly ($p < 0.05$) highest mean DM yield in Kapkerer and ICV 6 in Koibem (Table 10.4). In Kiptaruswo, a DM yield increase of 40 % was observed by variety ICV 6 (best DM yielder) compared with variety IT 83D-442 (poorest DM yielder), although at no significant different values

Table 10.3 Within – site effect of P – fertilizer application on cowpea DM yield (kg/ha) during LR 2009 in Nandi South District

		P rates (kg P/ha)			
Site	Cowpea varieties	0	15	30	Mean
Kapkerer site (LFS)	Enzegu	932	1,021	1,003	985a
	Ilanda	1,006	920	1,155	1,027a
	Khaki	796	744	768	769b
	Means	912a	895a	975a	
	Grand mean	927			
	SED$_{\text{(phosphorus)}}$	139			
	SED$_{\text{(variety)}}$	134			
	SED$_{\text{(Phosphorus × variety)}}$	244			
Kiptaruswo site (MLFS)	Enzegu	191	225	154	190a
	Ilanda	192	225	198	205a
	Khaki	109	150	141	133b
	Means	164b	200a	164b	
	Grand mean	176			
	SED$_{\text{(phosphorus)}}$	34			
	SED$_{\text{(variety)}}$	32			
	SED$_{\text{(Phosphorus × variety)}}$	57			
Bonjoge site (MHFS)	Enzegu	75	142	268	162a
	Ilanda	155	195	254	200a
	Khaki	55	34	274	121a
	Means	95b	124b	265a	
	Grand mean	161			
	SED$_{\text{(phosphorus)}}$	76			
	SED$_{\text{(variety)}}$	79			
	SED$_{\text{(Phosphorus × variety)}}$	137			
Koibem site (HFS)	Enzegu	359	348	527	411a
	Ilanda	327	425	362	371b
	Khaki	392	279	361	344b
	Means	359b	350b	417a	
	Grand mean	375			
	SED$_{\text{(phosphorus)}}$	65			
	SED$_{\text{(variety)}}$	65			
	SED$_{\text{(Phosphorus × variety)}}$	114			

SED Standard error deviation. Means with the same letter are not significantly different ($p < 0.05$). *LFS* Low fertility site; *MLFS* Medium Low Fertility Site; *MHFS* Medium High Fertility Site; *HFS* High Fertility Site

($p < 0.05$) (Table 10.4). In Bonjoge, variety CB 46 was the best DM yielder (1,401 kg/ha) showing an increase of 38 % compared with the poorest yielder; variety ICV 6. The effect of site significantly ($p < 0.05$) influenced the mean DM yield across varieties (Table 10.4). The highest significant ($p < 0.05$) mean DM yield of 1,767 kg/ha was observed in Kapkerer, which was an increase of 32 %, compared with Kiptaruswo, 43 % compared with Bonjoge and 24 % compared with Koibem (Table 10.4).

Table 10.4 Within – site effect of P – fertilizer application on cowpea DM yield (kg/ha) during SR 2009 in Nandi South District

		P rates (kg P/ha)			
Site	Cowpea varieties	0	15	30	Mean
Kapkerer site (LFS)	Khaki	2,719	3,045	2,443	2,736a
	ICV 6	1,971	1,709	2,091	1,924b
	ICV 12	2,445	1,945	1,310	1,900b
	CB 46	1,415	1,561	1,149	1,375c
	IT 90 K-284-2	1,132	1,677	1,136	1,315c
	IT 83D-442	1,152	1,119	1,793	1,355c
	Means	1,806a	1,842a	1,654a	
	Grand mean	1,768			
	SED $_{(\text{phosphorus})}$	244			
	SED $_{(\text{variety})}$	256			
	SED $_{(\text{Phosphorus} \times \text{variety})}$	424			
Kiptaruswo site (MLFS)	Khaki	1,422	743	2,084	1,416a
	ICV 6	2,632	992	1,338	1,654a
	ICV 12	973	961	1,651	1,195a
	CB 46	1,422	1,452	953	1,276a
	IT 90 K-284-2	1,500	1,846	669	1,338a
	IT 83D-442	1,272	1,161	1,103	1,178a
	Means	1,537a	1,192a	1,300a	
	Grand mean	1,343			
	SED $_{(\text{phosphorus})}$	267			
	SED $_{(\text{variety})}$	388			
	SED $_{(\text{Phosphorus} \times \text{variety})}$	634			
Bonjoge site (MHFS)	Khaki	1,417	1,331	1,406	1,385a
	ICV 6	1,101	1,250	691	1,014a
	ICV 12	1,127	1,030	1,069	1,075a
	CB 46	1,385	1,792	1,025	1,401a
	IT 90 K-284-2	862	1,958	1,030	1,283a
	IT 83D-442	1,028	1,080	1,663	1,385a
	Means	1,153a	1,407a	1,147a	
	Grand mean	1,236			
	SED $_{(\text{phosphorus})}$	189			
	SED $_{(\text{variety})}$	272			
	SED $_{(\text{Phosphorus} \times \text{variety})}$	467			
Koiben site (HFS)	Khaki	1,450	1,010	1,780	1,415ab
	ICV 6	1,454	1,994	1,974	1,807a
	ICV 12	1,212	1,435	1,735	1,462ab
	CB 46	1,055	927	1,308	1,097b
	IT 90 K-284-2	2,184	1,491	1,487	1,720a
	IT 83D-442	1,100	1,173	975	1,083b
	Means	1,409a	1,338a	1,544a	
	Grand mean	1,430			
	SED $_{(\text{phosphorus})}$	233			
	SED $_{(\text{variety})}$	312			
	SED $_{(\text{Phosphorus} \times \text{variety})}$	576			

SED Standard error deviation. Means with the same letter are not significantly different ($p < 0.05$). *LFS* Low fertility site; *MLFS* Medium Low Fertility Site; *MHFS* Medium High Fertility Site; *HFS* High Fertility Site

Within and Across Site Effect of P – Fertilizer Application on Cowpea Grain Yield During SR 2009 Experiment

Cowpea grain yield was harvested only in Bonjoge (MHFS) and Koibem (HFS) hence the results below are for these two sites (Table 10.5). No grain was obtained in Kapkerer and Kiptaruswo sites due to flower abortion that occurred from high flower thrips infestation after delayed spraying. Averaged across varieties, application of P significantly ($p < 0.05$) influenced grain yield production in Koibem (HFS) but not in Bonjoge (MHFS) (Table 10.5). However, in both sites, a larger increase in the mean grain yield was observed at 15 kg P/ha rate than at 30 kg P/ha when compared with the no P rate. At 15 kg P/ha rate, mean grain yield increases of 33 % (Bonjoge) and 62 % (Koibem) were observed relative to the no P rate (Table 10.5).

However at 30 kg P/ha rate, grain yield increases of 8 % (Bonjoge) and 10 % (Koibem) were observed relative to the no P rate. The mean grain yield was significantly ($p < 0.05$) influenced by varietal differences in Bonjoge (MHFS) and Koibem (HFS) (Table 10.5). In Bonjoge, variety CB 46 (434 kg/ha) gave the

Table 10.5 Effect of P – fertilizer application on mean grain yield at study sites during SR 2009 experiment

		P rates (kg P/ha)			
Site	Cowpea varieties	0	15	30	Mean
Bonjoge site (MHFS)	Khaki	228	182	506	306ab
	ICV 6	170	151	295	206b
	ICV 12	319	335	160	272ab
	CB 46	544	540	219	434a
	IT 90 K-284-2	161	228	262	217b
	IT 83D-442	121	615	229	322ab
	Means	257a	342a	278a	
	Grand mean	292			
	SED $_{\text{(phosphorus)}}$	85			
	SED $_{\text{(variety)}}$	119			
	SED $_{\text{(Phosphorus} \times \text{variety)}}$	200			
Koibem site (HFS)	Khaki	171	134	76	127b
	ICV 6	256	299	196	256ab
	ICV 12	214	347	466	342a
	CB 46	92	381	173	215ab
	IT 90 K-284-2	210	319	114	214ab
	IT 83D-442	88	188	108	128b
	Means	172b	278a	189ab	
	Grand mean	213			
	SED $_{\text{(phosphorus)}}$	49			
	SED $_{\text{(variety)}}$	66			
	SED $_{\text{(Phosphorus} \times \text{variety)}}$	104			

SED Standard error deviation. Means with the same letter are not significantly different ($p < 0.05$). *MHFS* Medium High Fertility Site; *HFS* High Fertility Site significantly ($p < 0.05$) highest grain yield compared with ICV 6 (206 kg/ha), an increase of 110 % (Table 10.5). In Koibem, however, variety ICV 12 (342 kg/ha) gave the significantly highest ($p < 0.05$) mean grain yield compared with Khaki and IT 83D-442, an increase of 169 %. The effect of site significantly ($p < 0.05$) influenced the mean grain yields of the cowpea varieties studied (Table 10.5). Averaged across varieties, a mean grain yield increase of 38 % was observed at Bonjoge (MHFS) compared with Koibem (HFS) (Table 10.5).

Discussions

Soil Chemical and Physical Characteristics of the Field Study Sites

Initial soil chemical characteristics exhibited a trend of declining soil fertility (N and P) and SOC stock. All sites showed low available levels of P (less than the 10 mg/kg considered critical for extractable P in soils) suggesting the need for supplemental addition. Continuous cultivation of these sites without or with minimal fertilizer replenishment partly resulted in the gradual depletion of soil P (Kinyangi 2008), hence the low levels of available P. Levels of total N and percentage SOC were considered high in Bonjoge and Koibem and low in Kiptaruswo and Kapkerer. This is partly because Kapkerer and Kiptaruswo have undergone longer and more intensive nutrient losses as a result of crop cultivation (60–105 years) and subsequent nutrient removal via crop exports, as well as through natural pathways for losses in soil nutrients, such as erosion and, leaching, compared with Bonjoge and Koibem (5–60 years). Generally, after forest harvest, cultivation accelerates the depletion of SOM, as nutrients held in decomposing forest litter are mineralized (Tisdale et al. 1990). Therefore, the transformations of C and nutrient losses are the direct effects of continuous cultivation without adequate soil amendments. Soil pH values were lower in Kapkerer and Kiptaruswo than in Bonjoge and Koibem. This may partly be attributed to the high rate of organic matter mineralization in the warmer and more humid environmental conditions in Kapkerer and Kiptauruswo than in the cooler and wetter conditions in Bonjoge and Koibem. The soil textural class for all sites was sandy clay loam except in Kiptaruswo. This can be partly attributed to the farmers' management practices and the soil characteristics of the different sites.

Effect of P – Fertilizer Application on Final DM and Grain Yield During LR and SR 2009 Experiments

There was no significant effect of P – fertilizer on DM yield, partly confirming the wide adaptability of cowpea to soil fertility variability and different environmental conditions. According to www.iita.org/cowpea, cowpea is well – adapted to soils of poor fertility and thrives in both semi – arid regions and sub – humid zones. Additionally, crop responses to P – fertilizer application, depend on many factors, such as soil characteristics, crop grown, climate, tillage systems, interactions with other nutrients, crop management and fertilizer management (Bordeleau and Prevost 1994). During the LR study, the mean DM yield increased with increasing levels of P in Kapkerer, Bonjoge and Koibem. This was partly attributed to the roles played by nutrient P in enhancing plant physiological functions of such processes as photosynthesis, N fixation, flowering, fruiting and maturation (Tisdale et al. 1990). When these processes are enhanced, DM accumulation is also enhanced. The application of P influenced grain yield production, although at a no significant value ($p < 0.05$) during the SR 2009 experiment. At 15 and 30 kg P/ha, the increase in mean grain yield was consistent with the findings, reported by Okalebo et al. (1997) and Vanlauwe et al. (2006) that soils from smallholder farms in western Kenya are predominantly P deficient and therefore require modest applications of P – fertilizers at recommended rates (FURP 1994), for increased and sustained crop yields. This finding partly confirms the beneficial effect of nutrient P on cowpea grain production (Vance 2001), since numerous studies have shown that P – fertilizers can significantly increase crop yields (Bationo et al. 1995; Kolawole et al. 2000).

Effect of Site on Cowpea DM and Grain Yield During 2009 LR and SR Experiments

The site effect significantly influenced mean DM and grain yields at both Kapkerer (LFS) and Koibem (HFS). Despite the low fertility status of Kapkerer (Kimetu et al. 2008), the highest mean DM and grain yields were recorded at this site, partly because of its favourable drier, warmer conditions and lower elevation compared with the cooler, wetter and higher elevations of the other sites. According to Singh et al. (1985), cowpea is a low – altitude plant, and is not usually grown above 1,200 m but thrives in warmer environmental conditions with low rainfall amounts. During LR, the three local varieties studied had the most potential for household vegetable use in Kapkerer. The ability of cowpea varieties to adapt to different agro – ecological conditions may explain the extent of the mean DM and grain yield obtained (Bagayoko et al. 2000). Generally, grain yields obtained were very low, partly due to the wetter and cooler environmental conditions of the sites.

Conclusions

Results from this study show that extractable P and total N were limiting at all sites, hence there was the need for external fertilization. Cowpea varieties screened within and across sites had different agronomic adaptation as influenced by heterogeneity in soil fertility and environmental conditions. Although productivity is influenced by the soil fertility status and environmental conditions of the sites, the application of P is essential for increasing both DM accumulation and grain yield.

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Chapter 11
Innovations to Overcome Staking Challenges to Growing Climbing Beans by Smallholders in Rwanda

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Abstract Climbing beans provide the best option for intensification and the production of surplus beans in Rwanda where arable landholdings are diminished. Shortage of staking wood is a major challenge limiting the wider adoption of the crop. Poor staking or none causes a yield loss of 50–90 %. Due to wood scarcity, this study was undertaken to evaluate feasible and farmer-acceptable innovations that avoid over-reliance on the wood staking while maintaining yield benefits. Six densities at 0 (zero staking), 15,000; 16,670; 20,000; 23,000 poles with trellises and 50,000 poles without trellises/ha^{-1} (normal practice) were used to stake adapted varieties ISAR-CB-105 (MAC 9) or ISAR-CB-102 (RWV 1129) in a randomized complete block design (RCBD) at six locations: Muhanga, Rubona, Rwerere, Nyagatare, Ngoma and Karama over three seasons in 2009 and 2010. Farmers' preferences for the staking innovations were assessed for the various treatments at physiological maturity growth stage of the crop. Grain yield differences across the treatments were determined by performing analysis of variance (ANOVA) using R- Statistical package. Total grain yields ranged from 180 to 6,200 kg/ha with means from 1,730 to 3,120 kg/ha The lowest value was observed in the zero-staked treatment (control) and the highest in 100 % wood staked (50,000 without trellises). Fully staked plots also produced the highest yields by 87 % across sites and seasons. However, the differences in mean grain yields were statistically insignificant at $P_{(0.001–0.005)}$ between all treatments except for the zero-staked plots

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where it was significantly lowest. Most farmers (92 %) preferred combinations of 16,670 wood stakes/ha with trellises that reduced the wood requirement by 67 % with a minimal reduction in yield of 6 % of the normal practice control. The fully wood staked treatment ranked fifth with 25 % preference and the zero-staked treatments ranked sixth (last) with 8 % preference. Although a gain in grain yield was important, farmers' choices depended most on the envisaged availability, labour implication, durability and cost of stakes. Selection criteria were segregated by gender. Environmental concerns were mentioned but featured least. Therefore, although the highest staking density maximized yields, it was viewed as the biggest challenge, especially among women farmers who were, in turn, most comfortable with the use of trellises. A strategic combination of stakes with trellises that caused the maximum reduction of the number of wooden poles and the minimum loss of grain yield benefits/unit area was the most acceptable option to overcome this challenge. Further study to provide empirical evidence of the cost–benefits of the different staking innovations is underway.

Keywords Farmers' acceptability • Agriculture intensification • Climbing beans • Grain yield benefits • Staking challenges and innovations • Women farmers

Introduction

Beans (*Phaseolus vulgaris* L.) constitute 85 % of vegetable sources and 65 % of all animal and plant sources of dietary proteins in Rwanda (Sperling et al. 1992). Climbing beans produce superior grain yields of 3.5–5.0 t/ha, that is, threefold the yield of bush beans. They are thus important for intensified production in Rwanda, where the shortage of arable land is acute with only less than 1 ha/household (Kalyebala and Mugabo 2005). Replacing 1 ha of bush beans with the climbing type produces an additional on-farm yield of about 2,000 kg/ha that is equivalent to an extra net income of US$400 (Sperling et al. 1992). Other advantages of climbing beans include better tolerance to fungal and other biotic stresses; staggered maturity and sequential consumption of green leaves and pods as well as fresh and dry grain that ensure continuous and diversified nutrition throughout a growing season (Sperling et al. 1992). A number of varieties recently released in Rwanda combine high yields and Fe and Zn contents (Musoni et al. 2012a, b), important for the alleviation of hunger and micro-nutrient malnutrition.

Adoption of climbing beans in Rwanda rose from 5 % in 1985 to 42 % in 1992, then to 60 % in 2005. However, most of the expansion was limited to the cool and humid northern highlands (1,800–2,300 masl) where adoption reached 95 % (Sperling et al. 1992; Kalyebala and Mugabo 2005). These conditions favour the proliferation of fungal diseases, particularly root rots to which bush beans succumb. The growing of climbing beans and the sourcing of stakes were therefore a conditional and inescapable alternative for the farmers, irrespective of any returns to investments.

Until recently, nearly all varieties of climbing beans released in Rwanda were for the highland and mid-altitude, 1,600–2,300 masl (Nyabyenda 1991). Most recently, however, the bean improvement programme in Rwanda came up with new varieties suitable for production in the low-altitude zones of the country (Musoni et al. 2010, 2012a, b). Even in the traditional highlands, the need for climbing beans to be staked has been the major limiting factor for maximizing yield benefits by the farmers. They can hardly afford the recommended rate of stakes (50,000/ha). Poor staking of climbing beans leads to a loss of 50–90 % in yield (ISAR 1987).

Optimal staking is limited by the shortage of adequate agro-forestry and tree species that are used in the region. These include *Pennisetum,* bamboo*, Alinus, Cacia, Calliandra, Sesbania, Leucaena, Eucalyptus* and *Grevillea species*. The challenge is most evident as limiting wider extension of climbing beans in new and non-traditional agro-ecological zones and regions that make up two-thirds of the bean growing area in Rwanda (Odendo et al. 2004; Musoni et al. 2005.) Continued use of wood for stakes could be in conflict with environmental protection, especially where afforestation and agro-forestry resources are not established.

Previous studies on staking innovations focused on the determination of optimal density, appropriate length, sources and durability. Little was done to address the problem associated with the lack of stakes. Studies included intercropping and relay cropping of climbing beans with maize (ISAR 1990, 1991). However, as beans (and maize) became commercial crops (Musoni et al. 2012a, b), monoculture has increasingly become a necessity. Continuous intercrops prevent beans–maize rotations and promote diseases. Relay cropping is, in many cases, prevented by rotations with other crops, such as potato. Furthermore, spacing between beans and maize in the intercrop are not in tandem and interfere with good husbandry practices.

To overcome these challenges, this study was initiated with the objective of developing alternative farmer-acceptable and environmentally friendly staking innovations that reduce the density of stakes while maintaining high productivity.

Materials and Methods

The research was conducted in two mid-altitude locations at Muhanga and Rubona (1,650 masl); one high-altitude site at Rwerere (2,300 masl); and three low- altitude locations at Nyagatare, Ngoma and Karama (1,400 masl) (Table 11.1).

Six levels (T1 to T6) of stake densities were designed: zero-staked–T6; 15,000; 16,670; 20,000; and 23,000 in combination with knitting thread, sisal or plastic trellises, and the normally used rate of 50,000 poles ha^{-1} without cross bars or strings (T1). This was designed by adjusting the normally used inter-pole distance of 0.4 m to 1.0 m 1.5 and 2.0 m and filling the gaps with trellises hanging at 0.4 m interval on/and supported by horizontal wooden bars or by strings (Table 11.2). T1 and T6 were used as controls. Locally adapted varieties of climbing beans with a standard yield potential of 4,000–5,000 kg ha^{-1}: *ISAR-CB-105* (MAC 9) for low

Table 11.1 Physical characteristics

Site	Longitude	Latitude	Altitude (masl)	Rainfall (mm year^{-1})	Mean annual temperature (°C)
Rubona	29° 46′ E	2°29′ S	1,650	1,171	18.7
Rwerere	30° 00′ E	1°30′ S	2,300	1,166	15.6
Nyagatare	30° 20′ E	1°20′ S	1,450	830	22.4
Karama	30° 16′ E	2°17′ S	1,403	850	20.8

Masl metre above sea level

Table 11.2 Summary of treatments for trials on staking innovations of climbing beans

Treat. no.	Intra-row pole spacing (m)	Other description	Total wood density (ha^{-1})
T1	0.4	No cross bars and strings	50,000
T2	2.0	Wooden cross bars with hanging strings	16,666
T3	1.5	Wooden cross bars with hanging strings	20,000
T4	1.0	Cross strings support other hanging strings	23,333
T5	Variable	Scattered poles tied on top in a cone shape	15,000
T6	–	No wood or strings used at all	0

altitude and *ISAR-CB-102* (RWV 1129) for mid = and high-altitude locations, were planted against the six staking options in the trials.

The experiments at each site were established in a randomized complete block design (RCBD) arrangement and replicated twice. The plot sizes were 6 m × 6 m and plots were planted with six rows of climbing beans. The spacing was 50 cm inter-row and 20 cm intra-row. Two seeds were placed in each station to give a plant population of 200,000 plants/ha Planting was done on ploughed and leveled soils after the application of mineral fertilizer (NPK 17:17:17) at the rate of 100 kg/ha. Weeding and earthing-up were done at the 6-leaf growth stage, followed immediately by staking. The trial was repeated across the six locations over three seasons of 2009 A, 2009 B and 2010 A. Two groups of 30 men and 30 women farmers evaluated and selected preferred innovations by tying red ribbons (for women) or black (for men) against the least preferred plots and blue ribbons (for women) or white (for men) against those most preferred at physiological maturity stages at Nyagatare and Rwerere research experiment sites. These were representative of a traditional and a new zone growing climbing beans. Choices of the 60 farmers for best and worst treatments were pooled and used to rank all the treatments. The farmers' choices among the different staking options were tallied and ranked and proportions of preferences were presented as a percentage.

Grain yield was determined after harvest and drying to 14 % moisture content. Grain yield differences across the treatments were determined by performing analysis of variance (ANOVA) using R-Statistical package.

Results and Discussion

There were highly significant differences among effects due to treatments, locations and seasons at $P_{(0.001–0.005)}$ (Table 11.3). This was attributed to extreme variation in the physical and climatic conditions at the six locations and during the seasons. However, the effect of interactions of treatments, location and season was insignificant. This could be the result of using single and adapted varieties at each location to determine the yield.

Normal wood staking (T1) produced the highest yields in four of the six locations with a frequency of 87 % across sites and seasons while zero-staking (T6) produced the lowest yields in comparison with other treatments (Table 11.5). The 100 % wood staked also had the highest (3,108 kg/ha) mean grain yield and zero-staked plots had the lowest (1,727 kg/ha). A similar trend in yield variation was observed in the maize–climbing beans trials (ISAR 1991) that recorded best yields of 3,045 kg/ha for the fully wood staked treatment and the poorest yield of 1,308 kg/ha for the zero-staked treatment.

By taking the grain yield of 180 kg/ha that was observed in T6 and 4,444 kg/ha in T1 at Karama and values of 1,529 kg/ha (T6) and 6,200 kg/ha (T1) at Rwerere, the loss in grain yield from a lack of stakes ranged from 69 to 96 % (Table 11.4). In maize–beans intercropping trials at Ntyazo in southern Rwanda in which the proportions of stakes were 100 %, 75 %, 50 %, 25 % and 0 % of the wood/maize

Table 11.3 ANOVA for treatment yield over six locations and three seasons

Source	DF	SS	MS	F value	P (>F)
Location (L)	5	150,992,426	30,198,485	81.0742	<2.2e-16***
Season (S)	2	30,815,385	15,407,693	41.3652	4.917e-14***
Replication (R)	1	896,536	896,536	2.4069	0.12375
Treatment (T)	5	45,500,111	9,100,022	24.4309	2.453e-16***
S × T	10	3,570,320	357,032	0.9585	0.48378
L × T	25	14,175,152	567,006	1.5222	0.07308
L × S	10	104,166,926	10,416,693	27.9658	< 2.2e-16***
L × S × T	50	16,532,591	330,652	0.8877	0.67617
Residuals	107	39,855,294	372,479		

Prob. range and codes: ***- Significant at P (0.001)

Table 11.4 Comparison of grain yields and yield losses associated with poor staking or none across six experimental locations and three seasons

	Grain yield (kg/ha)			
Location	Minimum	Maximum	Mean	Yield loss (%)
Karama	180	4,444	1,900	96
Ngoma	416	3,556	2,152	88
Nyagatare	1,667	5,333	3,545	69
Muhanga	611	2,944	1,689	79
Rubona	694	6,100	2,786	89
Rwerere	1,528	6,200	3,931	75
Mean	–	–	–	83

Table 11.5 Mean grain yield under the different staking innovations across six sites and three seasons in Rwanda (three seasons in 2009 and 2010)

			No. of locations treatment had	
Treatment (T)	Pole density (nr/ha)[1]	Mean yield (kg/ha)	Highest yield	Lowest yield
T1	50,000	3,108a	4	0
T2	16,666	2,928a	0	0
T3	20,000	2,900a	1	0
T4	23,333	2,849a	0	0
T5	15,000	2,492a	1	2
T6	0	1,727b	0	4
LSD		*698*		
SE		*144*		
CV		*13*		

NB: Figures with the same letter are not significantly different

population; and in the maize–beans relay-cropping trials, the yield losses attributed to zero-staking ranged from 41 to 67 % (ISAR 1987, 1991). These results show that the lack of stakes is still a major constraint affecting productivity.

The differences observed in ranges of yield losses from the old and current studies could be attributed to the broader diversity of test locations in the current study. This is also reflected in the variability in the mean grain yields that were obtained at the different sites. Rwerere, Nyagatare, Rubona, Karama, Ngoma and Muhanga had the highest means in that order. Varietal differences could also contribute to the expressed differences in mean grain yields in some sites, where different varieties were used (Table 11.4).

Despite the fact that the highest yields were consistently observed in fully staked plots, pair-wise comparison and statistical grouping of mean grain yields revealed there was no significant difference in yield due to the different treatments except in T6, where no staking was done (Table 11.5). This means that while the use of woody stakes remains the best recommendation to optimize the productivity of climbing beans, the wood/trellises combination is an equally significant option among smallholders without or even with established afforestation and agro-forestry systems. These results also confirm that zero-staking significantly constrained productivity.

The above was confirmed by results during the farmers' participatory evaluation. The zero-staked plots with the poorest yields were ranked last and preferred by only 8 % of the farmers. The fully wood-staked treatment was ranked second-last (fifth) and preferred by 25 % of the farmers, despite being the highest yielding. This poor ranking was recorded among new and traditional farmers growing climbing beans in the north and east of the country. Yield was an important consideration but the scarcity of the stakes was, however, the most important negative selection criterion among all the farmers.

The treatment that ranked first with 92 % preference was T2 where 16,670 stakes were combined with trellises. This option was more attractive to women farmers in particular as it reduced the burden of normal stakes without a significant loss in

Table 11.6 Number and percentage preferences of farmers' participatory evaluation of six treatments of staking innovations for climbing beans at Nyagatare and Rwerere in 2009 and 2010

		Farmers' preference		
Treatment (T)	Pole density (nr ha^{-1})	Number ($N = 60$)	Percentage (%)	Ranking
T1	50,000	15	25.0	5
T2	16,666	55	91.7	1
T3	20,000	42	70.0	2
T4	23,333	22	36.7	4
T5	15,000	41	68.3	3
T6	0	5	8.30	6

yield. In T2, the staking rate was reduced by 67 % and the yield loss was reduced by only 5.8 % of the best yielding, fully (100 %) staked treatment. In the live staking of maize in the maize–beans intercrop trials, the 50 % reduction in the wood population with a mean yield gap of 21.8 % of the 100 % wood-staked treatment was the best option that was recommended (ISAR 1991).

Although the choice of the zero-staking option was last, it is noteworthy. The farmers opting for this came from eastern Rwanda where bush beans predominate and wood for staking is very scarce. As shown (Table 11.4), yields of unstaked climbing beans are comparable with, or even higher than the grain yields of some of the best performing varieties of bush beans that ranges from 1,500 to 2,000 kg/ha (Nyabyenda 1991; Musoni et al. 2010). Indeed, an ongoing study has included an improved variety of bush beans as a check and preliminary results show comparable yields between this and the zero-staked climbing beans (Nyiramugisha et al. 2012).

Farmers' choices were influenced by time and labour during preparation and actual staking. Wood was scarce, expensive, cumbersome to cut, transport, trim and fix. Stakes were usually damaged by termites or stolen. However, wealthier farmers, especially men with better access to forestry resources, preferred wood stakes as these lasted longer, and they could afford them. Women farmers, on the other hand, were more patient and skilful than the men in the *weaving* techniques required while using sisal, plastic or thread trellises. Therefore, farmers preferred most staking innovations that strategically combined stakes with trellises; and significantly reduced the number of stakes/unit area without a corresponding significant reduction in grain yield benefits (Table 11.6).

Conclusion and Recommendation

The study established that the exclusive use of stakes at 50,000/ha was the best option to maximize potential yield benefits from climbing beans. However, given options, it was the least preferred by farmers since sources of wood from forestry and agro-forestry are inadequate, and stakes are costly and cumbersome, among other disadvantages. Farmers, especially the poor and women, favoured innovations that combined staking poles with more readily available trellises and reduced reliance on wood by 70 % with insignificant reduction in yields compared to normal wood-staking practice. Further studies and analysis of empirical data about the short and long-term cost benefits of the tested innovations to improve this study are ongoing.

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Chapter 12

Crop–Livestock Interaction for Improved Productivity: Effect of Selected Varieties of Field Pea (*Pisum sativum* L.) on Grain and Straw Parameters

G.G. Yetimwork, E.G. Awet, and M. Solomon

Abstract Straws from peas are richer in protein, calcium and magnesium than cereal straws, and if sustainably harvested, they are useful roughage feeds for ruminant animals. However, the available information on the nutritive and varietal effects on the dry matter (DM) yield of legume straws is scarce compared with that on cereal straws or grass hays despite the efforts to increase food production from peas. This study was therefore conducted with the objective of determining the chemical composition, digestibility and degradability of field pea (*Pisum sativum* L.) varieties. The study was conducted at Haramaya University Campus and Hirna Experimental Station, Ethiopia, during the 2011 cropping season. The experiment was established as a Randomized Complete Block Design (RCBD) with four replications. Five selected varieties were grown: Tegenech, G22763-2C, Markos, Adi and Local pea. Among the parameters determined were the leaf to stem ratio, straw DM yield, harvest index (HI), potential utility index (PUI), chemical composition, in vitro DM, in sacco DM, organic matter (OM) and neutral detergent fiber (NDF) degradability. The result showed varietal differences in grain yield, straw DM yield and straw quality. This indicated the possibility of selecting for varieties that combine high grain yield and desirable straw characteristics. According to the result of the experiment, Tegenech was identified as having a high yields in grain and straw DM. Local pea at Haramaya and Tegenech at Hirna were significantly ($P < 0.05$) higher in PUI than the remaining varieties. The value of PUI ranged from 29.2 to 41.7. The varieties were significantly different in the in vitro DM degradability at Haramaya whereas there was no significant difference at Hirna. At Haramaya, the variety G22763-2C had

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significantly higher in vitro DM degradability than Tegenech and Adi. There were also significant differences among the varieties for the plant cell wall. Except for the rate of degradability there was significant difference ($P < 0.001$) among the varieties for DM degradability both at Haramaya and Hirna, OM and NDF degradability at Haramaya.

Keywords Variety • Field pea • Dry matter • Chemical composition • Nutritional quality

Introduction

In Ethiopia, the majority of the cattle population (78 %) is reared in the highland settled crop farming area where the production of animal feed is a serious problem (FAO 1999). It is obvious that expansion in the cultivation of food crops increases the supply of crop residues for animal feeding and residues of different crops contribute 50 % of the total animal feed required in the crop–livestock farming area (Jutzi et al. 1987). Many Ethiopian farmers conserve crop residues for use during the critical period of the dry season. Field pea is an important pulse crop that covers about 175,000 ha and the annual production is estimated at about 150,000 t. Although it is grown primarily for human food, the plants can also be made into silage or hay and grown as a pasture crop in combination with oats or other small grains (Chapman 1982).

Peas belong to the genus *Pisum* and the species of *sativum*. It is an annual herbaceous plant, with a climbing or half-bush growth habit, reaching a height of 50–150 cm. The plant develops a tap root system with many slender laterals; the stems are weak, slender and succulent and have typically innately compound leaves, but the leaf is modified into a split or double tendril (Onwueme and Sinha 1991). This crop is best adapted to a cool climate with moderate rainfall, and a moderate temperature is essential throughout the growing season for its successful production. It survives light frosts, but not during flowering. Hot dry weather interferes with seed setting. Peas are grown in the winter (cooler) seasons in the tropics and are an important crop of higher elevations (more than 1,000 m), particularly in East Africa and DR Congo (Onwueme and Sinha 1991). According to Kossila (1984), straws from peas are richer in protein, calcium and magnesium than cereal straws, and if sustainably harvested, they are useful roughage feeds for ruminant animals. Although peas are a high protein food, like other grain legumes, they are somewhat deficient in the amino acids methionine and cystine. They are characterized by relatively high contents of crude protein (CP) and metabolisable energy (Igbasan and Guenter 1996).

However, the available information on the nutritive and varietal effects on the DM yield of legume straws is scarce compared with that for cereal straws or grass hays despite the efforts to increase food production from beans and peas (Geberhiwot and Mohamed 1989). Therefore, this study was conducted to determine the chemical composition, digestibility and degradability of five field pea varieties.

Materials and Methods

The Study Area

The study was conducted at two sites, Hirna experimental station and Haramaya University campus. Hirna is located at 41° 4′ E longitude and 9° 12′ N latitude and an altitude of 1,870 masl. It has a mean annual rainfall of 990–1,010 mm, with a mean temperature of 24 ° C. Haramaya University is located at 42° 3′ E longitude and 9° 26′ N latitude, at an altitude of 1,980 masl. The mean annual rainfall is 780 mm and the mean annual temperature is 23.4 ° C (HUA 1998).

Experimental Design and Treatments

The experimental treatments consisted of five varieties of field peas, Tegenech, G22763-2C, Markos, Adi and Local pea. These were selected on the basis of results from previous screening trials on their adaptation to the agro-ecological zone of the two sites. The varieties were arranged in a randomized complete block design (RCBD) in four replications.

Data Collection

Straw Dry Matter Yield, Grain Yield, Potential Utility Index and Harvest Index

Leaf: stem ratios were calculated by taking ten randomly selected plants from each plot. At maturity, all varieties were harvested to assess the straw DM yield that was calculated using the following formula (Tarawali et al. 1995).

$$SDMY(t/ha) = \frac{DM\% \times TFW(t/ha)}{100}$$

where

TFW = total fresh weight
DM% = DM percentage of the straw.
SDMY = Straw Dry Matter Yield

Grain yield was calculated as the total weight of seeds harvested/plot. The potential utility index (PUI) was calculated as the ratio of the grain yield plus the digestible DM yield of crop residues to the total above-ground biomass DM yield (Fleischer et al. 1989).

The in vitro DM degradability was used for the calculation of the digestible DM yield of the crop residue.

Harvest index (HI) was calculated as the percentage proportion of grain yield to the total above- ground DM yield (Fleischer et al. 1989).

$$HI = \frac{GrainYield}{TotalBiomassYield(t/ha)} \times 100$$

In Vitro Dry Matter Digestibility Procedure

In vitro DM digestibilities of the straw sample of each variety were determined by the method of Tilley and Terry (1963) as modified by Van Soest and Robertson (1985).

In Sacco Degradability Procedure

The dried straw samples were ground to pass through a 2 mm screen to determine DM, organic matter (OM) and Neutral Detergent Fiber (NDF) degradability. Rumen degradability of the samples were determined by incubating about 2.5 g of the sample in a nylon bag (41 μm pore size and 6.5 cm × 14 cm dimension) in three rumen fistulated Boran × Holestein Fresian steers kept at the Debre Zeit Research Station of the International Livestock Research Institute. The straw samples were incubated for 0, 3, 6, 12, 24, 48, 72, 96 and 120 h. The data of DM, OM and NDF degradability were fitted to the exponential equation described by McDonald (1981)

$$Y = A + B\left(1 - e^{-C(t-tl)}\right)$$

Where

Y = the potential disappearance of DM at time t
A = rapidly degradable fraction
B = the potential, but slowly degradable fraction
C = the rate of degradation of b
tl = lag time

Chemical Analysis

The dried samples of straw from each variety of field peas were ground to pass through a 1 mm screen to determine their chemical composition. The DM percentage was determined by oven drying the different samples at 105 ° C for 24 h. Total ash and CP contents were determined according to the procedure of AOAC (1990).

Ash was determined by completely burning the feed samples in a muffle furnace at 500 ° C overnight. The structural plant constituents, NDF, acid detergent fiber (ADF) and acid detergent lignin (ADL) were analysed using the detergent extraction method (Van Soest et al. 1991). Hemicellulose was calculated by subtracting ADF from NDF and the cellulose fraction was calculated as the difference between ADF and ADL.

Statistical Analysis

Data on agronomic parameters and straw DM yield were subjected to analysis of variance (ANOVA) using the statistical software MSTAT-C (1989). Data for the chemical composition and for the degradability of in vitro DM, in sacco DM, OM, and NDF were analysed using the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS 1998). Treatment means were separated by least significance difference (LSD).

Results

Leaf-to-Stem Ratio, Grain Yield, Harvest Index and Potential Utility Index

There was no significant difference ($P > 0.05$) in leaf-to-stem ratio, HI and PUI for the field pea varieties at both sites; however, some varieties had a relatively better leaf-to-stem ratio than the others.

There was significant difference ($P < 0.05$) in grain yield among the varieties at both sites. Local pea and Tegenech yielded significantly more grain than G22763-2C and Adi at Haramaya. Tegenech also produced a higher grain yield than the other varieties at Hirna.

There was a significant difference ($P < 0.05$) of HI and PUI among the varieties at both experimental sites. Tegenech was significantly better in HI than the other varieties at both sites. Local pea at Haramaya and Tegenech at Hirna were significantly ($P < 0.05$) higher in PUI than the remaining varieties. The value of PUI ranged from 29.2 to 41.7.

Straw Dry Matter Yield, Straw-to-Grain Ratio and In Vitro Dry Matter Digestibility

There was a significant difference ($P < 0.05$) in the straw DM yield among the varieties (Table 12.1). Markos (12 t/ha) and Adi (11 t/ha) produced significantly

Table 12.1 Mean straw dry matter yield, straw to grain ratio and in vitro dry matter digestibility

	SDMY (t/ha)		Straw to grain ratio (kg/kg)		IVDMD (% DM)	
Varieties	Haramaya	Hirna	Haramaya	Hirna	Haramaya	Hirna
Tegenech	8.36^{b}	7.97^{c}	3.44^{b}	3.09^{b}	69.2^{b}	69.5
G22763-2C	8.11^{b}	9.59^{b}	$5.67^{a,b}$	$7.48^{a,b}$	74.1^{a}	69.1
Markos	7.89^{b}	12.44^{a}	$4.98^{a,b}$	10.41^{a}	$70.5^{a,b}$	70.1
Adi	10.74^{a}	9.53^{b}	7.21^{a}	$5.79^{a,b}$	66.9^{b}	69.6
Local pea	5.93^{c}	7.97^{c}	3.56^{b}	4.6^{b}	$70.7^{a,b}$	67.9
Significance level	***	***	***	***	*	ns
S.E.M	0.1	0.3	0.2	0.1	0.6	0.6
C.V (%)	3.4	6.2	9.7	7.0	2.0	2.1

Means followed by different superscripts in column are significantly different
S.E.M = standard error of mean, *C.V* = coefficient of variation, *ns* = non significant, *SDMY* = straw DM yield, *IVDMD* = in vitro DM digestibility
* $P < 0.05$; *** $P < 0.001$

higher straw DM yields than the other varieties. The varieties at both sites were significantly different in the value of the straw to grain ratio that varied from 3.44 (Tegenech) to 2.21 (Adi) with the mean value of 4.97.

There was a significant difference in the in vitro DM digestibility values at Haramaya but no significant difference at Hirna. At Haramaya, the variety G22763-2C had a significantly higher in vitro DM digestibility value than Tegenech and Adi (Table 12.1).

Chemical Composition

Except for the ash and OM values at Haramaya, there was no significant difference among the varieties. The CP result in this study was more than 6.7 % which is higher than the findings of Geberhiwot and Mohamed (1989) in the same species.

Neutral Detergent Fiber, Acid Detergent Fiber and Acid Detergent Lignin

The NDF content ranged between 39 % (G22763-2C) and 53 % (Local pea) at Haramaya and from 43 % (Adi) to 49 % (G22763-2C) at Hirna (Table 12.2). Therefore, there were significant differences among the varieties for the plant cell wall. Also the ADF value ranged from 32 % (G22763-2C) to 46 % (local pea) at Haramaya and from 34 % (Markos) to 36 % (G22763-2C) at Hirna. Similarly, the lignin content ranged from 4.8 % (G22763-2C) to 7.7 % (Local pea) at Haramaya and from 5.0 % (Tegenech) to 6.4 % (Local pea) at Hirna.

Table 12.2 Neutral detergent fiber, acid detergent fiber, acid detergent lignin, cellulose and hemicellulose contents of field pea varieties at Haramaya and Hirna

	NDF (% DM)		ADF (% DM)		ADL (% DM)		Cellulose (% DM)		Hemicellulose (% DM)	
Varieties	HU	HI	HU	HI	HU	HI	HU	HI	HU	HI
Tegenech	46.2^{b}	46.5^{ab}	37.6^{b}	36.1^{a}	5.3^{bc}	5.0^{c}	32.2^{c}	30.1^{ab}	8.6^{a}	11.1^{ab}
G22763-2C	39.1^{d}	48.7^{a}	31.8^{c}	36.2^{a}	4.8^{c}	5.9^{a}	26.8^{d}	31.2^{a}	7.3^{b}	11.82^{a}
Markos	46.0^{b}	43.9^{bc}	38.7^{b}	33.9^{b}	5.6^{b}	5.1^{bc}	33.1^{b}	29.2^{ab}	7.4^{b}	9.6^{cd}
Adi	43.5^{c}	43.0^{c}	38.4^{b}	34.3^{ab}	5.8^{b}	5.9^{ab}	32.7^{bc}	28.5^{b}	5.1^{d}	9.0^{d}
Local pea	52.9^{a}	46.4^{ab}	46.4^{a}	35.9^{ab}	7.7^{a}	6.5^{a}	38.7^{a}	29.5^{ab}	6.6^{c}	10.4^{bc}
Significance level	***	***	***	***	***	***	***	***	***	***
S.E.M	0.5	0.8	0.4	0.5	0.1	0.2	0.2	0.6	0.1	0.2
C.V (%)	2.5	3.7	2.3	3.1	5.6	8.0	1.3	4.9	4.0	4.2

Means followed by different superscripts in column are significantly different
S.E.M = standard error of mean, *C.V* = coefficient of variation, *NDF* = neutral detergent fiber, *ADF* = acid detergent fiber, *ADL* = acid detergent lignin, *Cellulose* = NDF-ADF, *Hemicellulose* = ADF–ADL, *HU* = Haramaya, *HI* = Hirma
***$P < 0.001$

Table 12.3 In sacco OM degradability parameters of field pea varieties at Haramaya

Varieties	*A* (% DM)	*B* (% DM)	C (%/h)	*TL* (h)	*PD* (% DM)	*ED* (% DM)
Tegenech	43.5^{c}	30.2^{a}	0.08	4.2^{c}	73.7^{ab}	51.1^{b}
G22763-2C	55.1^{a}	21.4^{b}	0.06	4.5^{c}	76.5^{a}	57.7^{b}
Markos	51.5^{ab}	20.6^{b}	0.13	6.8^{b}	73.1^{ab}	65.6^{a}
Adi	51.1^{ab}	19.3^{b}	0.06	10.0^{a}	70.4^{b}	53.4^{b}
Local pea	50.6^{b}	19.9^{b}	0.05	5.8^{b}	70.5^{b}	53.2^{b}
S.L	***	***	ns	***	**	***
S.E.M	0.7	0.4	0.00	0.2	0.7	1.2
C.V	3.0	4.2	11.8	6.8	2.3	4.7

Means followed by different superscripts in column are significantly different ($P < 0.001$, 0.01)
A = rapidly degradable, *B* = insoluble, but potentially (slowly) degradable component, *C* = the rate of degradation of 'B' component, *TL* = lag time, *PD* = potential degradability (A + B), *ED* = effective degradability at outflow rate of 0.03 h^{-1}, *S.E.M* = standard error of mean, *C.V* = coefficient of variation, *S.L* = significance level, *ns* = non significant
*** = $P < 0.001$; ** = $P < 0.01$

In Sacco Dry Matter, Organic Matter and Neutral Detergent Fiber Degradability

Except for the rate of degradability there was significant difference ($P < 0.001$) among the varieties for DM degradability at Haramaya and Hirna, OM and NDF degradability at Haramaya (Tables 12.3 and 12.4).

Table 12.4 In sacco NDF degradability parameters of field pea varieties at Haramaya

Varieties	*A* (% DM)	*B* (% DM)	*C* (%/h)	*TL* (h)	*PD* (% DM)	*ED* (% DM)
Tegenech	15.00^{b}	44.2^{a}	0.06	8.10^{a}	59.2^{a}	21.3^{b}
G22763-2C	14.39^{b}	35.4^{b}	0.11	3.52^{b}	49.8^{b}	28.7^{b}
Markos	8.67^{c}	41.1^{ab}	0.14	3.51^{b}	49.7^{b}	41.7^{a}
Adi	6.27^{c}	41.0^{ab}	0.06	7.20^{a}	43.0^{c}	11.3^{c}
Local pea	29.96^{a}	24.3^{c}	0.14	6.05^{ab}	54.2^{ab}	45.3^{a}
S.L	***	***	ns	**	***	***
S.E.M	0.6	1.2	0.0	0.5	1.1	1.4
C.V	8.5	6.0	15.3	20.0	4.7	10.4

Means followed by different superscripts in column are significantly different $P < 0.01$ or highly significantly different $P < 0.001$

A = rapidly degradable, *B* = insoluble, but potentially (slowly) degradable component, *C* = the rate of degradation of 'B' component, *TL* = lag time, *PD* = potential degradability (A + B), *ED* = effective degradability at outflow rate of 0.03 h^{-1}, *S.E.M* = standard error of mean, *C.V* = coefficient of variation, *S.L* = significance level; *ns* = non significant

*** = $P < 0.001$

Discussions

Leaf-to-Stem Ratio, Grain Yield, Harvest Index and Potential Utility Index

Some of the varieties (G22763-2C, Local pea) which take relatively longer time to mature had a lower leaf to stem ratio value than the other varieties. This is also noted by Butt et al. (1993) who observed that the leaf-to-stem ratio decreases as the plants advance in maturity. In this study, the varieties producing a high grain yield, Local pea at Haramaya and Tegenech at Hirna, had a significantly higher HI. The varieties producing poor grain yields, Adi at Haramaya and Markos and G22763-2C at Hirna, had a significantly lower HI than the other varieties. Varietal differences in HI were also reported in different maize varieties (Tolera et al. 1999) and in ten varieties of tef (Bediye et al. 1996). Generally, the varieties with high grain yields had a higher HI than those producing lower grain yields.

Tegenech was higher in yields of grain and straw. This indicates the possibility of selecting for varieties that combine higher yields in both grain and straw. The PUI of the current study indicated a higher result for Tegenech. This shows the possibility of selecting varieties for straw yield and quality without detriment to the grain yield. Measurement of the PUI of a crop is a good parameter in this respect as it integrates grain yield and digestible DM yields from the residues (Fleischer et al. 1989). The PUI result of the current study was lower than that of different varieties of tef straw (Bediye et al. 1996).

Straw Dry Matter Yield and In Vitro Dry Matter Digestibility

The straw DM yield in the current study varied from 5.9 to 12.4 t/ha. The varieties gave a higher straw DM value than that reported for different varieties of barley in the highland of Ethiopia (Bediye 1995), and stover yield of maize (Tolera et al. 1999). The varieties were similar in straw DM yield to the different varieties of oats (Fekede 2004).

In this study, the in vitro DM digestability value of the field pea straws varied from 67 to 74 %. The result of the current study showed a higher value of in vitro DM digestibility than that of native grass hay (Getachew Eshete 2002), wheat straw (Coxworth et al. 1981), oats and vetch mixture (Birhanu 2004). Meissner et al. (2000) reported that in vitro digestibility values greater than 65 % indicate good nutritive value, and values below this level result in a reduced intake due to lowered digestibility. The values obtained in the present study were higher than this critical level.

Chemical Composition

The values of CP (CP) in the current study were similar to those reported by Kossila (1984), which ranged between 10 and 15 %. The CP content of field pea in this study was higher than that of maize stover (Tolera et al. 1999) and cereal straws (Bediye and Sileshi 1998). The mean CP content was higher than the critical value of 7 % for normal rumen microbial action and feed intake (Van Soest 1982). According to Nsahlai and Umunna 1996, roughage feeds with a CP content of 9.9–15 % were classified as high quality, those from 6.6 to 9 % as medium and those from 3 to 6.5 % as low. The varieties evaluated in this study could thus be classified as high quality feeds with respect to their CP contents.

Neutral Detergent Fiber, Acid Detergent Fiber and Acid Detergent Lignin

The NDF content of the varieties in this study lies within the range of 33–53 %. This result was lower than the critical level of 55–60 %, which was reported to decrease voluntary feed intake and feed conversion efficiency due to the longer rumination time (Shirley 1986). According to Singh and Oosting (1992), these field pea varieties are average quality feed since their NDF lies between 45 and 65 %.

The ADF results of this study were lower than the values reported for straws from field pea (Geberhiwot and Mohamed 1989), cereal and oil crops (Bediye and Sileshi 1989), and tef (Bediye et al. 1996) and maize stover (Tolera et al. 1999). The lower value of ADF in this study could be indicative of better digestibility than in other straws.

Lignin is a compound, which attributes strength and resistance to plant tissue, thereby limiting the ability of the rumen micro-organisms to digest the cell wall polysaccharides (Reed et al. 1988). These become more digestible once the lignin has been removed (Jones and Wilson 1987). Therefore, those varieties with higher lignin contents could have lower digestibility than those with lower lignin contents.

In Sacco Dry Matter, Organic Matter and Neutral Detergent Fiber Degradability

Generally the DM degradability characteristics of field peas at both sites were better than those of maize stover (Tolera et al. 1999), tef straw (Melaku 2001) and the field pea straw results of Bruno-Soares et al. (1999). The results of OM degradability constants of field pea varieties were higher in *a*, *c*, *ED* than the value reported for tef straw (Melaku 2001). Except for the rate of NDF degradability, the field pea varieties had lower NDF degradation constants than tef straw (Melaku 2001).

Conclusions

In the current study, the different varieties of field peas had higher CP, lower fiber contents and relatively higher for insacco degradability than different varieties of cereal straws and maize stover. In addition, the result showed some significant varietal difference in grain yield, straw DM yield, PUI, HI, chemical composition and degradability. Tegenech had higher grain and straw yields followed by the local check. This indicates the possibility of selecting varieties that combine a better grain yield with desirable straw and, generally, the variability indicates the need for consideration of both grain and straw parameters.

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Chapter 13

From Standards to Practices: The Intensive and Improved Rice Systems (SRI and SRA) in the Madagascar Highlands

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Abstract In the Betsileo Highlands of Madagascar, the supposedly great potential of SRI (System of Rice Intensification) and SRA (Improved Rice System or *système de riziculture améliorée*) has not been concretized by massive adoption by farmers. The lowest adoption rate occurred in and around forest protected areas where SRI extension was implemented early on to help farmers face conservation constraints. The hypothesis was put forward that the SRI model has either encountered specific ecological and socioeconomic constraints or has not matched the promises made by those who promoted it. An *in situ* agronomic survey at field level (crop management sequences, yield component analysis) was implemented on random samples of farmers' fields, with about fifteen fields per system. Three systems were compared: neither SRI nor SRA (control S1), application of SRI (S2), application of SRA (S3) at two sites (near the forest, near the markets) for 3 years. The control S1 was more intensive and higher-yielding than SRI/SRA promoters indicated: 4.2 t/ha against 2 t/ha in official discourses. The management of S2 and S3 matched the prescribed models SRI and SRA for key features overall. However, S2 generally received more organic manure and more fertilizers than S1 and S3 and benefited from the best preceding crops and the best paddies. The average yield of practiced SRA (S3) was not different from S1, because S1 had sometimes already adopted some features of SRA. Near the forest, with peat soils and mainly mineral fertilizing provided by conservation projects, there was no difference between S1 and S2 yields in 2006 (drought in vegetative phase), therefore the 2007 yield of S2 exceeded S1 by 14 % (only due to bigger ears). Yet near the markets in 2008, with mainly mineral soils, counter-season crops, earlier rains, and more manure, the S2 yielded +40 % more than S1 with more panicles. The average gain of +24 % included effects of fertilizer and manure additions, and so the real SRI effect,

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ceteris paribus was much lower. This low attractiveness, the associated risks, the cost of specialized hired labor, and the lack of manure and fertile mineral soils probably reduced SRI adoption by the poor farmers of the forest and forest edge. Near roads and markets, more people had enough manure and money for hiring workers to invest and run the risks of SRI. But the real SRI effects have yet to be checked, in *ceteris paribus* yields, environmental and social benefits.

Keywords Rice • Intensification • SRI • Madagascar • Environment • Highlands

Introduction

In the central highlands of Madagascar above 1,000 m asl, paddy rice plays a leading role as a foodstuff, in the labor calendar, and in social relations. The terraced rice landscape demonstrates the substantial know-how of Betsileo and Merina farmers in questions of rice growing (Blanc-Pamard and Rakoto-Ramiarantsoa 1993). The former Betsileo common rice production system consisted of growing local varieties, with specific tillage hand tools (*angady*), once a year in lowland or terrace paddies fed by handmade water systems. After deep tillage, manuring, flooding, trampling, and levelling, the usual planting method consisted of sowing in a tilled, manured, and irrigated nursery and then transplanting together several seedlings 1–2 months old at a high density and setting deeply in liquid mud. Flooding was continuous and one or two manual weeding operations were performed. Many variations were observed due to climate, water control, soils, varieties, cropping calendar, manure amount etc. Environmental constraints (peaty soils, lack of manure availability, climate constraints) and collective technical actions were emphasized to explain a general yield average of 2 t/ha. In good conditions, yield exceeded 3 t/ha (Dufournet and Rabemanantsoa 1961). Despite such diversity of practices and yields, this former local cultivation system is often referred to as "SRT (traditional rice system) yielding 2 t/ha".

A technical model that is more demanding as regards capital and labor called "improved rice growing" or *fomba nohatsaraina* was extended in the 1960s. It did not reject local practices (except mass transplanting) but added new features and required more work, including inorganic fertilization, good choice of variety, rational nursery, seedlings of less a month, treatment of seed, transplanting in rows, careful crop maintenance, mechanical weeding, and control of beetles (Dufournet and Roche 1967). Since 1995, non-governmental organizations (NGOs) and national extension system projects have attempted to extend new intensive models of SRI and SRA in a context of population pressure and policies for the conservation of natural areas.

SRI (system of rice intensification) is a local innovation that is becoming an international standard for rice development. SRI has been extended officially in Madagascar since 1995. It was originally designed in eighties by a group of agricultural students with support from H. de Laulanié, a priest and agriculturalist and then disseminated by Association Tefy Saina (ATS), his NGO (Laulanié 1991, 1993, 2003). This civil society proposal is based on four interdependent principles that contrast with local practices and improved standards: (1) the transplanting of very young seedlings (<15 days) in sticky mud, (2) planting one by one at low density (16/m^2), in crossed rows, (3) in the vegetative period, phases of shallow flooding (<2 cm) are alternated with drained periods, and (4) repeated mechanical weeding (Laulanié 1993; Vallois 1995). The SRI alternative model was promoted to the national level with support from the Agriculture Department and the World Bank in the 1990s and to the international level with the support of CIIFAD, a Cornell University department. This standard was described as a high tillering and very high yielding system without chemical input requirements (Laulanié 1991, 1993, Vallois 1995; Uphoff and Randriamiharisoa 2002).

SRA (*système de riziculture améliorée*/improved rice growing system) is a renaming of the 1960s “improved rice growing” since SRI’s launch.

It is more than ever necessary to examine what happened to these earlier introduced, improved, and recent intensive rice growing standards with the hindsight afforded by their early introduction in Madagascar. One should assess their true capacity to be adopted and attain the subsistence, income, and well-being objectives of populations of rice farmers with limited access to land and inputs. This is especially the case of SRI what is described as a high-yielding, pro-poor, and agro-ecological standard (Uphoff and Randriamiharisoa 2002; Stoop et al. 2002). This standard has been extended since 1994 in zones subject to forest conservation constraints where SRI was presented as an alternative to slash and burn (DAI 2004), justifying support (training, supplies on credit) provided by NGOs and internationally funded projects to the Koloharena farmers groups. A viewpoint other than that of previous research, based only on socioeconomic inquiries (Moser and Barrett 2003) is needed to respond to these concerns. It is necessary to compare the various field data rather than unverified normative affirmations and local opinions, examine how resources are used in practice, compare their productivity and find the deep-seated reasons for acceptance or rejection.

The framework of agronomic analysis of practices (Milleville 1987) makes it possible to approach the field reality of farming systems and to explore the many dimensions of techniques once they have been put to use. The technical acts and crop-soil systems are studied when they are performed throughout the production process, at their scale of application, and in their natural locations—farmers’ fields. Other aspects of practices are then explored if necessary by investigations at other scales.

Methodology

The field study was conducted in the South-Highlands region near Fianarantsoa and Androy commune, where Dufournet and Rabemanantsoa (1961) carried out a survey and where SRI started in 1994 and was assessed by Moser and Barrett

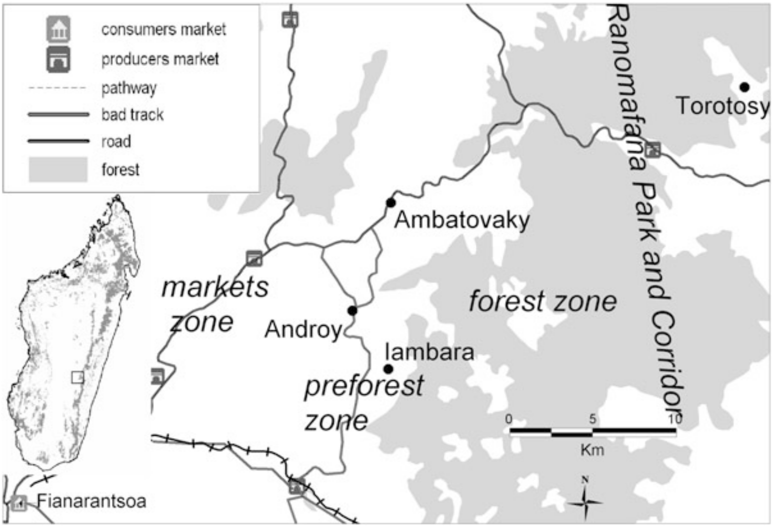

Fig. 13.1 Study zone (Source: FTM BD500 and authors)

(2003). This zone has three sub-zones: the forest zone close to Ranomafana National Park (survey in 2006), the preforest zone (survey in 2006 and 2007), and the markets zone close to roads (survey in 2008) (Fig. 13.1). SRI and SRA were extended continuously in both market and preforest zones with incentive measures.

The local adoption rate was reported by official surveys in Fianarantsoa region in 2002 and measured by Moser and Barrett (2003) and our census in Iambara, a village in Androy commune in 2006. Three types of rice growing practices were compared at field scale: neither SRI nor SRA (S1 = control), application of SRI (S2), and application of SRA (S3). The inner colder forest zone with peaty soils has only S1 practices and is therefore rejected for systems comparison. The choice of plots was made during the peak harvest period (mid-February to mid-March). Information was gathered in a few villages where the SRI practice existed concerning rice fields that had reached maturity. This was used to make a random choice of neighboring fields with different systems, with a target of 15 fields of each practice each year. At the site, a plot homogeneous as regards environment and management was identified and surveyed with the farmer as regards area, information about soil and water, previous crops, crop management system, measurement of yield components, expenditure and duration of labor, soil, weeds, and crop states at the different phases. The final data basis contains a total of 127 plots for the three zones. The average results were compared by ANOVA (XLSTAT© program). For yield components measurement, five randomized microplots measuring 2 m^2 were harvested. Two samples of straw and panicles were taken for measurement of moisture and for grain counts in the laboratory.

Results

Practices

Local Adoption Rates

After a decade of extension, the two technical standards have been variously accepted. In 2002, in the central part of Fianarantsoa highlands, SRI accounted for 1.5 % of the area, SRA 11.5 %, direct seeding 2 %, and mass transplanting 85 % (MAE-UPDR 2002). The warm zones with two crops had not yet adopted SRI. SRA thus seems to be more widely adopted than SRI but it must be said that it inherited the adoption of the "improved rice growing" of the 1960s. The common mass transplanting practice has withstood 50 years of political pressure, training, and incentives for transplantation in rows. However, this still a marginal aspect of the adoption of the new intensive standards in terms of area contrasts with the number of people who adopted and tested it. In the Haute Matsiatra region around Fianarantsoa, 15 % of communes make regular use of SRI and 28 % use it at least occasionally (Instat 2003). A proportion of this scale indicates a good level of learning and a varied degree of interest, but in contrast the small areas seem to indicate that caution is still the watchword, including among people who adopt the system.

The varied degree of interest depends on the local situation: in the forest zone there was no SRI in 2006. In the landlocked preforest zone of Iambara, the census made by Moser and Barrett (2003) and ourselves showed a process of experimentation of SRI followed by a process of progressive abandonment. Yet SRI practices are still well adopted in the road and markets zone (Ambatovaky) (Table 13.1).

Calendar of Operations

The crop management sequences for the introduced systems (S2, S3) differed mainly in more standardized calendars and early soil preparation than S1, the frequent presence of a counter-season crop (especially in S2 but also in S3), more weedings in S2 (2–4), and more frequent inorganic fertilization in S2 and S3.

Table 13.1 Rate of SRI practicing farmers according to zone and date

	Ambatovaky	Iambara	Torotosy
	Road and market zone	Land-locked pre-forest zone	Low elevation pre-forest zone
% experimenting (1993–98)	48	16	27
% practicing (1999)	26	7	0
% practicing (2006 or 2008)	26	3	0

Sources: 1993–99: Moser and Barrett (2003); 2006 Iambara: authors census; 2008 Ambatovaky and Torotosy: Koloharena group

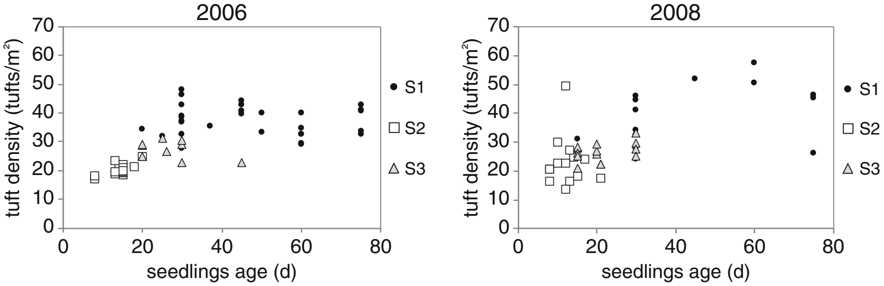

Fig. 13.2 Transplanting layout: seedling age *versus* tuft density (2006: pre-forest + forest zone; 2008: markets zone) (S1: control; S2: local application of system SRI; S3: local application of SRA) (Source: authors)

Tools Used

Tillage was performed using the *angady* and ox-drawn plough or both, depending on the system. Two ploughings were generally performed after harvest and before transplanting. However, there were slight differences in puddling. Harrowing was used more in S2 and S3 than in S1 where trampling was used more. Puddling in S2 was never minimal as it was in some S1 plots (consisting just of clod breaking and levelling with an *angady*). Indeed, weeding in S1 was always by hand. Rotary weeders were used in one case out of two in S2 and S3. Hand weeding was performed, especially when conditions were muddy. S2 and S3 thus used more mechanical tools and S1 often used oxen trampling.

Transplanting Layout

The transplanting layout was strongly characteristic of the systems (Fig. 13.2). While the 2006 and 2008 surveys were conducted in different zones, transplanting features were very similar and a clear distinction can be made between the three systems:

- S1: seedling age > 30 days, >30 tufts/m^2, mass, 1–3 seedlings per tuft
- S2: seedlings <20 days, <25 tufts/m^2, in rows sometimes crossed, 1 seedling per tuft, 20 cm between tufts
- S3: seedlings 15–30 days, 20–30 tufts/m^2, no crossed rows, 1–3 seedlings per tuft, 15 cm between tufts

Finally, S1 is the traditional layout but denser than former surveys, S2 corresponds quite perfectly to SRI transplanting principles, and S3 appears as an intermediate layout between S1 and S2.

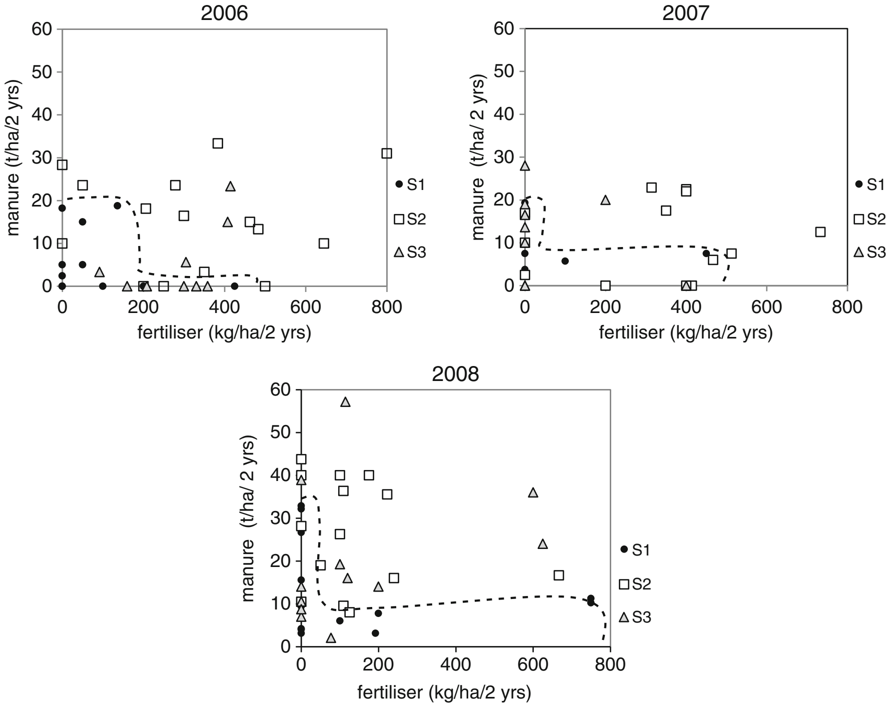

Fig. 13.3 Aggregate mineral fertilizer and manure applied over a two-year period (2006 and 2007: pre-forest zone; 2008: markets zone) (S1: control; S2: local application of system SRI; S3: local application of SRA) (Source: authors)

Water Regime

S1s and most of the S3s used the classic water regime: maintaining more than 2 cm water or, in rainfed paddies, maximum filling. Management of the S2s and three S3s is very specific, aiming at keeping a water depth of less than 2 cm in the rice field and drainage after weeding operations, corresponding to the SRI principle. With this aim, S2 is used in rice fields with good mastery of water, and this rules out most of the poorly drained peat soils in and near the forests.

Fertility and Fertilization Regime

Preceding counter-season crops (mineralized manure, remains of fertilizer, better redox status) are more frequent in S2. S2 also prefers more fertile, neighboring village soils. S2 avoids deep peaty soils, where there is too much water. These soils are difficult to transplant small seedlings into and to weed using a machine, because the soil bearing capacity is low. These constraints explain a part of the rarity of S2 in the forest and preforest zones.

The fertilization regime is important as a practice correcting soil fertility and crop yield build-up: an indicator is the sum of the fertilizer doses applied over a 2-year period (Fig. 13.3).

S1 stands out from the two others with weak or imbalanced fertilization strategies: “no fertilizer”, “low manure only”, or “low fertilizer only”. S2 generally received a large mixture of fertilizers with an emphasis on mineral fertilizer in the preforest zone (thanks to conservation project credit programs) and on manure in the market zone villages with substantial numbers of oxen and pigs. Huge quantities of manure were applied in many S2 plots and a few S3 plots.

Varieties Used

Each year, S1 displayed the most local varieties while S2 and S3 favored improved varieties.

Biological Effects

Climatic Conditions

Although irrigation is used, rainfall plays a role by determining the risks of dry periods and inundation of rice fields where water management is inadequate and periods of light reduced. Tropical depressions and cyclones accompanied by flooding and wind were observed over the study period:

- 2005–2006: rainfall deficit in October (transplanting) and in January (during heading) and February (fruiting)
- 2006–2007: rainfall deficit in October (transplanting) and December (tillering), continuous rainfall in January–February (fruiting)
- 2007–2008: deficit in December (tillering), cyclone on mid-February (flowering of late plantings).

The Biological Development of Rice

Early planting gain in terms of duration of vegetative functioning. The different systems in this study had similar ranges of planting dates, thus justifying the comparisons across the 3 years covered. The effect of the different practices on the duration of the crop cycle was generally negligible. In contrast, other S1 fields cropped in the inner forest in 2006 displayed a cycle 10 days longer for the same transplanting date than at the forest edge. The lateness is the sign of colder conditions. The altitude is higher, and the forest soils had more peat and more water.

Comparing S1 Yields Between Zones

The differences in S1 yields between locations are significant: forest: 2.91 t/ha (b); pre-forest: 4.04 t/ha (a) and markets zone: 4.34 t/ha (a). Panicle weight is the component accounting for the difference (2.0 g in pre-forest against 1.5 g in forest, significant difference at $P = 0.05$). This means that fruiting conditions are involved and are particularly bad in the forest zone (peat soils, poor fertilization, poor light, cold conditions, and pests). In markets zones, compared to the pre-forest zone, yielding is the same, yet panicle number is greater but weight smaller: there are more fertile mineral soils around oxen, more manure, and more counter-season crops.

Comparing Yields and Yield Components Between Practices (Pre-forest and Markets Zones)

The average results of the different systems were compared using analysis of variance (Table 13.2).

Control practice S1 (neither SRI nor SRA) gave average paddy rice yield of 4.17 t/ha. Practice S2, combining the principles of SRI and numerous additions, gave a significantly higher yield than S1 (5.16 t/ha = +24 %), but differed according to year: there was no significant difference in 2006, +14 % in 2007 (both years in preforest zone), and +40 % in 2008 (near markets). In 2008, the maximum yield of S2 was 8.2 t/ha, that is to say +24 % in comparison with the maximum for the control S1. Panicle number only increased in 2008 (markets zone), but the heads were small. Panicle weight only increased in 2006 and 2007 (preforest zone).

Practice S3 (SRA) did not show any significant increase in comparison with the control S1 as numerous SRA features were already incorporated in the latter.

Discussion

This study provides original data on rice growing practices and their results, as seen in an agronomic survey. Indeed any empirical survey has limits (dependence on what farmers say, risks of confusions between effects, limited number of plots). Further analysis and experiments are needed to test the hypothesis generated by this survey.

There is a low and decreasing adoption rate of SRI in and near the forest zone but SRI seems to be better adopted near roads and markets by many farmers. Indeed SRI encountered local natural and human constraints near forests that have to be explained. The local opinions we gathered in 2006 supported the reports of the promoters (Serpantié et al. 2007). SRI was adopted to “save seed”, even in plots with an area of a few hundred square meters, or for the “huge yields”, that is to say

Table 13.2 Average yielding of the different practices surveyed from 2006 to 2008 (S1: control; S2: local application of system SRI; S3: local application of SRA) (different letters: significant difference between practices for the corresponding year at $p < 0.05$) (+p%: average increase over the control S1) (Source : authors)

	2006			2007			2008					
	Pre-forest zone			Pre-forest zone			Markets zone			Total		
	S1	S2	S3									
	Control	SRI	SRA	S1	S2	S3	S1	S2	S3	S1	S2	S3
Number of plots	11	15	9	8	14	9	15	14	14	34	43	32
Tuft density (tufts/m^2)	37.3a	20.3c	27.3b	33.0a	22.6c	28.0b	39.2a	23.2b	26.5b	37.1a	22.0c	27.1b
Dry vegetative biomass (g/m^2)	164b	219a	193ab	199	212	188	288	350	293	227	259	235
Dry paddy yield (t/ha)	3.87	4.59	4.08	4.27ab	4.85a (+14 %)	3.72b	4.34b	6.08a (+40 %)	5.15ab	4.17b	5.16a (+24 %)	4.45b
Maximum yield (t/ha)	5.9	6.9	5.1	5.2	7.1	5.2	6.8	8.2	6.7	6.8	8.2	6.7
Fertile tillers density (panicles/m^2)	210	216	222	240	224	224	258b	318a	286ab	238	252	250
Panicle weight (g)	2.09	2.29	2.02	1.97b	2.32a	1.79b	1.69	1.92	1.83	1.89 b	2.18a (+16 %)	1.87b

the normative arguments of those in favor. This indicated many unspoken views about the costs of this type of rice cultivation, production expectations, and deep-seated motivations. Those who did not adopt SRI mentioned unsuitable soils, and too much labor, care, and expense (hired skilled transplanters and weeders). The arguments were thus incomplete. A closer investigative approach was therefore needed to go beyond these automatic or incomplete responses.

The so-called traditional practice i.e. “neither SRI nor SRA” (S1) yielded more than twice what is generally stated: 4.17 t/ha against 2 t/ha according to SRI promoters (Laulanié 1993). Dufournet and Rabemanantsoa (1961) already found yields of 3–3.5 t/ha in the best paddies, those where SRI is currently practiced. Therefore overall yields have increased by about 1 t/ha since 1961.

S1 still largely featured traditional characteristics (dense mass transplanting, frequent local varieties, manual tillage and weeding, organic manuring and trampling). The currently popularized double ploughing was not described by Dufournet and Rabemanantsoa (1961) nor prescribed by new rice standards and may be an innovation by local farmers to perfect drainage in the dry season. The current density of transplanting has also increased since Dufournet and Rabemanantsoa (1961). These changes in local rice growing confirmed that a “traditional practice” does not mean anything in itself anymore. Moreover, use was often made of certain “improved rice growing” features (fertilizer, draught tillage, improved varieties, counter-season crops) although it was not referred to as SRA since mass transplanting was performed. Indeed, row sowing was the only “visible” criterion recognized as SRA by technicians and farmers. These changes have already been described by Rollin (1993).

The second key result of this paper is that SRI adopters privileged their plots. The recommended principles of the SRI standard were not only globally respected in S2 but farmers “added a little more”. They applied complements to the basic recommendations. Thus S2s focused on fertilization (including inorganic fertilizer), improved varieties and best locations. Many S2s received huge amounts of manure. These additions were not among the Laulanié’s recommendations for farmers, although complete freedom was left to the latter. Comparisons to other practices are therefore not *ceteris paribus* i.e. “all things being equal”.

The great effects of location on control results and on the differences between practices reveal the complex natural or human factors affecting crop results, and hence the great limits of any “standard” since they do not take these variations into account. Near forests, peat soils are reductive, acid, and poor suppliers of nitrogen and phosphorus, the water is excessive (so-called “cold soils”). Climate is colder, and there are many pests (rats and birds). There is not enough manure available. Neither SRA nor SRI gives any answer to these constraints and farmers need help to drain these soils, and to obtain varieties and fertilizers for cold conditions. SRI is not an alternative to slash-and-burn for forest and pre-forest farmers.

S1 and S3 have no differences in yield as the practices are in fact similar. The best features of “improved rice growing” were adopted, except rows. SRA is not an attractive innovation in this zone since much of it has already been adopted, but perhaps some features of SRA are still good to test, but independently from SRA (P fertilizer on seedlings roots, deep seated urea, etc.)

Thanks mainly to bigger panicles, a yield advantage of about +24 % of S2 over S1 exists. It matches the results of Sinha and Talati (2007) and Senthilkumar et al. (2008), who found in surveys in India a yield increase of about 30 % with SRI. But, the advantage depends crucially on the zone and year: not significant in 2006, +14 % in the preforest zone (2007), and +40 % in the market zone (2008). SRI benefit crucially depends on climate, soils, and local economy.

But the real difference *ceteris paribus* is much smaller than 24 % because S2 often has an advantage in each cropping system feature (amount of fertilizers, preceding crops, best soils etc.). Manure or fertilizer doses and certain other important cropping system features such as choice of soils, tillage and preceding crops are not well described in cited science papers from India.

Civil society agriculturalists (Laulanié 1991, 1993; Vallois 1995), economists (Uphoff and Randriamiharisoa 2002; Minten et al. 2006; Jenn-Treyer et al. 2006), agro-ecology theorists (Stoop et al. 2002), and bodies awarding priority to SRI were too optimistic. Their early justification of SRI used theoretical discourses at only the plant level (the “Katayama model of tillering”) more than experimental evidence or agronomic survey at field level. To launch this system, they used an emphatic communication policy based both on SRI high tillering and huge maximum yields, and on scorning common on-farm yields. Yields thus “increased from 2 tons per ha of paddy rice to 8 or even 12 tons” (Laulanié 1993, p 110). In rhetoric, the economists and agro-ecology theorists unreservedly cited the same high yielding estimates. Later they added pro-poor and pro-environment arguments despite the low level of adoption.

Experimental agronomists had doubts about the results claimed for SRI right from the beginning (Razakamiaramanana 1995; Sinclair and Cassman 2004; Sheehy et al. 2004; McDonald et al. 2006), some recognizing only a possible yield benefit in soils marked by iron toxicity (Dobermann 2004; McDonald et al. 2006). In our region of study, Tsujimoto et al. (2009) examined the soil in SRI fields that had given “yields like those of a Japanese agricultural competition” and found exceptional nitrogen fertility and neither chemical or physical constraint: it was more an effect of the location (village soil) or intensive organic fertilization and deep tillage than any “agroecological synergy”.

Our results confirm these doubts.

In the preforest zone, especially with organic soils and mineral fertilization, low manure, and late rains, the real advantage of SRI *ceteris paribus* seems very low and very far from the promises of the promoters of this standard and those who extended it near parks and corridors. Panicle number/m^2 was the same for the three practices. Constraints and risks (peat soils, low manure availability, rats, late rains) and a small increase in average yields show that SRI was not suitable for the pre-forest zone. Some adopting farmers seek above all to use the funding opportunities provided by the projects, with practicing SRI or SRA being the condition for being accepted in the Koloharena group and obtaining fertilizer input credit and other social benefits.

The greater adoption and bigger raw effects of SRI near roads and markets needs special discussion. There is more manure, more money to hire skilled workers, and better soils than near the forest. There were early rains in 2008 too. More people can run the risks linked to SRI. The conditions to express an optimal difference between SRI and other practices may therefore be manure availability, richer soils, better control of water, and early rains, but these hypotheses should be checked by closer data analysis and experimentally if possible. But we have to specify the real difference in yield between S1 and S2 *ceteris paribus*. Indeed, the average SRI yield advantage will be much lower than 24 %. The optimism of promoters should be questioned again as the SRI cultivation system is now presented as "agroecological". For example, huge quantities of manure are applied on SRI plots in the market zone, against any ecological wisdom.

Conclusions

These results first confirm the "intensive" quality of the S1 common small farmers' system practice, based to a considerable degree on Malagasy principles. But the system is far from fixed and has changed by itself or with improved rice growing features since the 1960s and it looks like SRA, except for row transplanting. SRA therefore no longer seems to be a useful standard to be promoted in this zone. It shows that farmers are not "tradition keepers" but are very interested in other ways of doing things and their interest in testing SRI appears, firstly, as an exploration of techniques that go further than usual local standards more probably than a real interest in SRI itself.

The lack of attractiveness of real SRI yields, the greater efforts needed, the cost of specialized hired labor, the peaty soils, and the climate and pests risks probably reduced interest in SRI for the resource-poor farmers of the forest and the forest edge. It was not an alternative to "slash and burn" practices for them.

However, the fact that converted farmers favor the introduced system in a proselytizing manner at the expense of their economic results raises new questions as well as the fact that SRI academic promoters and conservation projects were markedly uncritical of SRI average productivity itself, at the expense of financial, development, and conservation results.

Yet in the market zone where conditions are better, the difference between practices seems greater but it has to be checked *ceteris paribus* because SRI plots are particularly over-fertilized (cf Serpantié and Rakondrondramanana 2013).

This paper shows, finally, that a policy based on technical standards in agricultural extension is far from optimal. It favors "marketing" discourses and excessive practices. It scorns unfairly common practices. It marginalizes crop science. It creates mistrust between farmers and other agricultural stakeholders. It is better to wait for more understanding of innovations before extending them everywhere. Definitely, farmers need more relevant advices than standard advices only seen as new "products" to launch at a country scale.

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Chapter 14

Identification of Elite, High Yielding and Stable Maize Cultivars for Rwandan Mid-altitude Environments

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Abstract Environmental and biotic stresses, such as drought, low fertility, diseases and weeds, are causing annual losses of million tons of maize grain in sub-Saharan Africa. The utilization of drought tolerant, extra-early maturing, disease and insect resistant maize varieties with Nitrogen Use Efficiency (NUE), has boosted maize production in areas where drought and disease are severe. Experiments were conducted with the objective of identifying suitable maize varieties for the mid-altitude environment that are tolerant to drought and resistant to infestations of Maize Streak Virus (MSV) and Turcicum Leaf Blight (TLB). The experiments were conducted in four sites (Rubona, Bugarama, Nyagatare, Karama) in Rwanda during the 2009 B and 2010 A seasons. They consisted of nine new hybrid varieties, seven new open pollinated varieties (OPVs), one hybrid check and four OPV checks. The AMMI (Additive Main Effects and Multiplicative Interaction) model for grain yield was used to analyse data. It showed that grain yield variation due to environments, genotypes and Genotype by Environment Interaction (GEI) was highly significant ($p < 0.01$). However, genotype effects accounted for 53 % of the sums of squares of treatments while environment accounted for 31 % and GEI effects for 16 %. The AMMI 1 biplot showed that drought tolerant and extra-early maturing cultivars were the most stable across environments. The AMMI 2 biplot showed that two OPVs were the least sensitive to the changes in the environments, and harsh environments exerted strong interactive forces on genotypes. Analysis of AMMI 1 and AMMI 2 biplots allowed six elite cultivars to be identified for the mid-altitudes which were stable across environments —CML442/CML440//CML445 (9.77 t/ha), CML312/CML202//CML445 (8.79 t/ha), CML144/CML159//CML182 (8.02 t/ha), NYA1 (Pop Nyag) (8.70 t/ha), RUB2 (DTLWN1) (7.99 t/ha) and ECA_EPOP1 (5.88 t/ha). The hybrid variety CML442/CML440//

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CML445 was drought tolerant, hence it was suitable for the semi-arid mid-altitudes; the hybrid cultivar CML312/CML202//CML445 combined resistance to MSV and TLB. The hybrid variety CML144/CML159//CML182 was a Quality Protein Maize (QPM). The OPV NYA1 combined several traits including earliness, resistance to foliar diseases and tolerance to drought. The variety RUB2 had desirable grain quality in addition to resistance to foliar diseases. Variety ECA_EPOP1 was extra-early and attained full maturity in 100 days after planting.

Keywords Additive Main Effects and Multiplicative Interaction (AMMI) • Biplot • Genotypes by Environments Interaction (GEI) • Grain yield • Mid-altitudes • Stable varieties

Introduction

Environmental stresses, such as deficiencies in nitrogen (N) and water, cause annual losses amounting to millions of tons of maize grain (Shou et al. 2004). The losses are even higher when the two stresses (drought and low N) occur together; this is the situation in developing countries, particularly in sub-Saharan Africa (SSA) where limited resources do not allow additional N and irrigation to be supplied (UNDP 2012). Maize Streak Virus (MSV) and Turcicum Leaf Blight (TLB) are among the major biotic stresses in countries of tropical Africa, including Rwanda, causing yield losses of up to 100 % depending on the infestation rate, time of planting (early versus late), season and moisture conditions (Magenya et al. 2008).

Van Eeuwijk (2006) presented the model expressing the phenotype of individuals in the presence of Genotype by Environment Interaction (GEI) as $P = G + E + GE$ where P was the phenotype, G = the sum of the genotypic contribution, E = environmental contribution and GE = the GEI. The environments may comprise locations, years, levels of fertilization, different plant densities and combinations. Any physical features that distinguish one experiment from another can constitute a different environment (Kang 1990).

The existence of genetic variability has allowed a significant breakthrough in the developing, testing and releasing of stress tolerant or resistant maize cultivars in target areas. The Multi-Environment Testing (MET) system has contributed to the selection of particular genotypes that are relatively stable for recommendation in specific sites. MET systems were facilitated by the availability of improved experimental designs, computer packages to handle complex designs, appropriate and enhanced models to analyse and interpret GEI (Edmeades et al. 2006).

Maize (*Zea mays* L.), traditionally grown in the highlands (Ngaboyisonga 2004), has had a rapid expansion in the mid-altitudes of Rwanda over the past 10 years, particularly with the advent of the Crop Intensification Program in 2006 (Cantore 2011). These mid-altitudes are heterogeneous environments with altitudes ranging from 900 to 1,700 m above sea-level. Climatic conditions range from semi-arid zones with approximately 800 mm/year of rainfall to well-watered conditions with precipitation more than 1,200 mm/year. They are characterized by severe infestations of foliar diseases, particularly MSV and TLB. There are two seasons in the year, the first (season A) starting in mid-September and ending in February and the second (season B) beginning in mid-February and finishing in July (Ngaboyisonga et al. 2007). The expansion of the maize crop to the mid-altitudes of Rwanda was not immediately accompanied by the release and the utilization of improved varieties. The objective of this study was to identify suitable and stable cultivars for the mid-altitudes of Rwanda.

Materials and Methods

Twenty-one maize genotypes, including nine new Three-Way Cross Hybrids (TWCHs) and seven new Open Pollinated Varieties (OPVs) were used in this study. One released hybrid variety and four released OPVs were used as checks (Table 14.1). The TWCHs were generated from CIMMY's inbred lines: CML442, CML440, CML445, CML444, CML312, CML202, CML204, CML342, CML254, CML258, CML343, CML341, CML144, CML159, CML176 and CML182.

The population NYA1 was developed by crossing ZM series from CIMMYT-Zimbabwe and local ecotypes with Pool-32 from CIMMYT-Mexico. In an isolated crossing block, in 2002, the ZM series and local ecotypes were female rows while Pool 32 occupied male rows. Female rows were detasseled. Only detasseled plants were harvested and the ears obtained were considered half-sib families. In 2003, a selection among the ears recombined and advanced the best 20 families from F_1 to F_2.

The variety RUB 2 was developed in 2002 by using kernels collected from accessions of several materials tolerant to drought and low-N from CIMMYT-Kenya. The kernels were planted in an isolated plot in 2002 and selection was performed for adaptability. All plants not selected were detasseled so that they could not provide pollen. In 2003, selection was performed among the obtained ears and 10 superior families were recombined and advanced from F_1 to F_2.

The variety KAR1 was developed using extra-early materials from CIMMYT-Zimbabwe. All introduced accessions were planted in an isolated plot in 2000. At harvest, the 25 best families were chosen and shelled in bulk. In the 2001 season, the bulk was planted in isolation and ears obtained were recombined in 2002. The varieties ECA-EPOP1, ECAVL1/ECAVL16STR and ECAVL5 were introduced from CIMMYT-Kenya; [TUX-SEQC6]C1 was introduced from CIMMYT-Mexico. The check hybrid variety H513 was released in Kenya whereas the four OPVs, Kigega, Ndaruhutse, ISARM081 and Katumani, were released in Rwanda.

The varieties were evaluated in four sites, Rubona, Nyagatare, Bugarama and Karama (Table 14.2), in the seasons 2009 B and 2010 A, making eight evaluation environments (site × season). Rubona site is the coolest and the highest (in altitude) and receives, on average, 1,171 mm rain/year. In this site, the incidence of diseases on maize is moderate and drought occurs occasionally. The Bugarama site has the lowest altitude in the country; it is the hottest of the sites considered and a hot spot

Table 14.1 Genotypes evaluated in mid-altitudes of Rwanda in 2009 B and 2010 A

No.	Code	Pedigree/names	Type of variety	SIL	ASI	GY
1	V01	CML442/CML440//CML445	Hybrid	70.2 ± 0.6	2.3 ± 0.1	9.77 ± 0.32
2	V02	CML312/CML202//CML445	Hybrid	74.1 ± 0.5	2.3 ± 0.1	8.79 ± 0.34
3	V03	CML144/CML159//CML182	Hybrid	74.6 ± 0.6	2.2 ± 0.2	8.02 ± 0.28
4	V04	CML342/CML258//CML202	Hybrid	76.6 ± 0.7	2.8 ± 0.1	5.86 ± 0.24
5	V05	CML343/CML258//CML202	Hybrid	75.9 ± 0.9	2.7 ± 0.2	6.70 ± 0.30
6	V06	CML442/CML444//CML202	Hybrid	74.3 ± 1.0	2.8 ± 0.2	6.17 ± 0.26
7	V07	CML144/CML159//CML176	Hybrid	72.5 ± 0.8	2.9 ± 0.1	6.42 ± 0.32
8	V08	CML442/CML444//CML204	Hybrid	77.3 ± 0.7	2.8 ± 0.1	6.09 ± 0.29
9	V09	CML341/CML254//CML202	Hybrid	72.3 ± 0.9	2.6 ± 0.2	6.17 ± 0.25
10	V10	H513	Hybrid, Released	75.4 ± 0.6	3.2 ± 0.1	5.09 ± 0.32
11	V11	NYA1 (Pop Nyag)	OPV	71.9 ± 0.4	2.4 ± 0.1	8.70 ± 0.27
12	V12	RUB2 (DTLWN1)	OPV	74.5 ± 0.4	2.8 ± 0.1	7.99 ± 0.25
13	V13	ECA_EPOP1	OPV	64.8 ± 0.5	2.7 ± 0.1	5.88 ± 0.14
14	V14	[TUX-SEQC6]C1	OPV	77.5 ± 0.6	3.1 ± 0.1	5.63 ± 0.22
15	V15	ECAVL1/ECAVL16STR	OPV	80.3 ± 0.6	3.1 ± 0.1	5.68 ± 0.25
16	V16	KAR1 (Karama 1)	OPV	65.6 ± 0.6	2.9 ± 0.1	5.96 ± 0.10
17	V17	ECAVL5	OPV	80.7 ± 0.6	3.2 ± 0.1	5.53 ± 0.21
18	V18	ZM607 (Kigega)	OPV, Released	72.7 ± 0.6	2.5 ± 0.1	7.13 ± 0.24
19	V19	POOL32 (Ndaruhutse)	OPV, Released	72.7 ± 0.6	2.5 ± 0.1	6.54 ± 0.23
20	V20	Katumani	OPV, Released	68.3 ± 0.4	3.3 ± 0.1	3.52 ± 0.13
21	V21	ISARMO81	OPV, Released	68.4 ± 0.7	2.6 ± 0.1	5.55 ± 0.32
Means			–	73.4 ± 0.2	2.7 ± 0.1	6.53 ± 0.08
C.V. (%)			–	1.2	19.3	10.40
F			–	***	***	***

SIL: Silking (days); *ASI*: Anthesis–Silking Interval (days); *GY*: Grain yield (t/ha); ***: Significant at $P < 0.001$

of MSV. The site experiences drought occasionally. Nyagatare site is the hot spot of TLB; at Karama, drought is very frequent and more severe than in other sites. All four sites have two cropping seasons in a year that overlap in February.

The experimental design used was Randomized Complete Design (RCBD) with four replications. A plot was made by two rows of 5 m length with 0.75 m between rows and 0.25 m between hills. Two grains/hill were planted and thinned to one plant/hill 3 weeks after planting. Fertilizer (NPK 17-17-17) was applied at planting at a rate of 300 kg/ha to give a nutrient rate of 51 kg N/ha, 51 kg P_2O_5/ha and 51 kg K_2O/ha. Six weeks after planting, 46 kg N/ha in the form of urea (46-0-0) was applied as top dressing. The sites were rainfed. Weeding was done as it was needed.

Table 14.2 Characteristics of evaluation sites in the mid-altitudes of Rwanda

Station	Lon.	Lat.	Altitude (m)	Precipitation (mm year^{-1})	Average annual temperature °C	Stresses
Rubona	29° 46″ E	2° 29″ S	1,650	1,171	18.7	Diseases (moderate), drought occurs occasionally
Bugarama	29° 00″ E	2° 28″ S	900	1,000	28.0	Hot spot of MSV, drought occurs occasionally
Nyagatare	30° 20″ E	1° 20″ S	1,450	831	22.4	Hot spot of TLB, drought occurs frequently
Karama	30° 16″ E	2° 17″ S	1,403	853	20.8	Diseases (moderate), drought is very frequent

Grain yields at harvest were obtained by weighing the total number of ears harvested in the plot and then obtaining the fresh weight in kg (FW). At the same time, a sample of kernels was taken in the middle of 10 selected ears and used to determine the percentage grain moisture (GM) using a portable moisture-meter. Ears were thereafter dried at constant moisture, weighed to have the dry weight (DW) in kg and then shelled to obtain the grain weight (GW) in kg. The grain yield in t/ha was obtained using the following relationship.

$$\mathrm{GY} = 10 \times \frac{\mathrm{FW}}{\mathrm{A} \times (\mathrm{B} + \mathrm{C}) \times \mathrm{D}} \times \frac{100 - \mathrm{GM}}{100 - 15} \times \frac{\mathrm{GW}}{\mathrm{DW}}.$$

Where:

A refers to the distance (m) between rows and B to the distance (m) between hills at planting, C is the length (m) of harvested rows, and D is the number of rows harvested.

Other agronomic traits observed were silking and anthesis-silking interval (ASI). Silking was recorded as number of days from planting to when 50 % of plants in the plot showed silks. The ASI was obtained by the difference between silking and anthesis. Hence, the anthesis was also recorded by considering the number of days from planting to when 50 % of the plants in the plot shed pollen.

Statistical Analysis

The AMMI (Additive Main effects and Multiplicative Interactions) was used to analyse the Genotype × Environment Interaction (GEI) for grain yield (Gauch 1992). The means and IPCA1 (Interaction Principal Component Axis) scores were used to form the AMMI 1 biplot; IPCA1 and IPCA2 scores were used to form the AMMI 2 biplot. The AMMI analysis of variance was performed using Genstat statistical computer package, Discovery, 3rd Edition (Buysse et al. 2004). Biplots were constructed using MS Excel spreadsheet.

Results and Discussions

The AMMI analysis of variance for grain yield of the 21 genotypes across eight environments showed that the variation due to genotypes, environments and GEI was highly significant ($p < 0.01$). The genotype effects accounted for 53 % of the treatment sums of squares (SS), and environments accounted for 31 % whereas GEI explained only 16 % of the treatment SS. The variation due to genotypes was 1.7 times larger than that of environments and 3.3 times larger than that of GEI. The variation due to environments was 1.9 times larger than that of GEI.

In AMMI analysis of variance, the treatment variation is subdivided into three types: variation due to genotype main effects, variation due to environments main effects and variation due to GEI effects. These three sources of variation present different problems and opportunities to agricultural researchers: the genotypes variation pertains to broad adaptations, the GEI variation pertains to narrow adaptations, and genotypes and GEI variations jointly determine mega-environments (Gauch 2006).

In the present study, the variation due to genotype main effects was more important than that of GEI effects, implying that broad adaptation was more important than narrow adaptation (Gauch 2006). Likewise, there are studies on various crops, including maize, where it was found that genotype variation was more important than the two other components (Ntawuruhunga et al. 2001; Ananda et al. 2009; Arulselvi and Selvi 2010) or that environment variation was the more important of the other two components (Mwololo et al. 2009; Beyene et al. 2011; Tonk et al. 2011; Sadeghi et al. 2011). However, it seems that instances where environment variation was dominant have been more frequent (Yan et al. 2005).

The AMMI analysis of variance showed that the first five IPCAs (Interaction Principal Component Axes) were highly significant ($P < 0.001$) (Table 14.3). IPCA 1 axis captured 44 % of the GEI SS in 19 % of the GEI degrees of freedom and IPCA 2 explained 26 % of the GEI SS in 11 % of the GEI degrees of freedom. Both IPCA 1 and IPCA 2 captured 70 % of the GEI SS in 36 % of the GEI degrees of freedom. The first two IPCA axes were helpful in predicting and analysing the complexity of the GEI from this study because AMMI selectively recovers the pattern in the first IPCAs whereas the last IPCA axis recover mostly the noise; the intermediate axis recover a mixture of pattern and noise (Gauch 1992).

The AMM1 1 biplot was used to assess the stability of varieties across environments. In the AMMI 1 biplot, the usual interpretation of a biplot is that displacements along the abscissa indicate differences in main (additive) effects, whereas displacements along the ordinate indicate differences in interaction effects.

Table 14.3 AMMI (Additive Main Effects and Multiplicative Interaction) analysis of variance for grain yield

Sources of variation	DF	SS	MS	F	P
Total	671	2726.7	–	–	–
Treatments	167	2493.4	14.93	32.43	<0.001
Genotypes	20	1325.5	66.27	143.97	<0.001
Environments	7	765	109.29	212.34	<0.001
Replications within environments	24	12.4	0.51	1.12	0.318
GEI	140	402.9	2.88	6.25	<0.001
IPCA 1	26	178.3	6.86	14.9	<0.001
IPCA 2	24	104.8	4.37	9.49	<0.001
IPCA 3	22	43.1	1.96	4.26	<0.001
IPCA 4	20	33.7	1.68	3.66	<0.001
IPCA 5	18	26.6	1.48	3.2	<0.001
Residuals	30	16.4	0.55	1.18	0.233
Error	480	221.0	0.46	–	–

Varieties that group together have similar adaptation while environments which group together influence the genotypes in the same way. When a variety and an environment have the same sign on the IPCA axis, their interaction is positive and if the signs are different, their interaction is negative. If a variety has high mean (mean $>$ overall mean) and an IPCA 1 score closer to zero (near the abscissa), it has small interaction effects and it is considered as stable across environments (Gauch 1992).

The AMMI 1 biplot (Fig. 14.1) showed that genotypes V01 (CML442/CML440//CML445), V02 (CML312/CML202//CML445), V03 (CML144/CML159//CML182), V11 (NYA1) and V12 (RUB2) had higher means (>7.9 t/ha) and small IPCA 1 scores ($-0.3 <$ IPCA score $< +0.3$). The variety V01 (CML442/CML440//CML445) had the highest yield of 9.77 t/ha across environments and the smallest IPCA 1 score of approximately 0.05. This drought tolerant genotype could always give the highest yield even in harsh environments such E03 (Karama-2009 B) or E08 (Bugarama-2010 B). Furthermore, genotypes V13 and V16, although they had grain yields less than 6.53 t/ha (general mean), had small IPCA 1 scores (<0.25) and hence did not interact with environments to an important extent. The two genotypes are extra-early maturing varieties (Table 14.1), hence drought- escaping, and thus giving comparable yields in all environments. Several studies have used also the AMMI 1 biplot to identify elite genotypes in various crops including maize (Ntawuruhunga et al. 2001; Arulselvi and Selvi 2010; Banik et al. 2010; and Hassanpanah 2011).

The AMMI 2 biplot presents the spatial pattern of the first two IPCA axes and helps in visual interpretation of the GEI patterns and identifies varieties or locations that exhibit low, medium or high levels of interaction effects. Genotypes near the origin are non-sensitive to environmental interactive forces and those distant from the origin are sensitive and have large interactions. Cultivar and site vectors are defined as vectors from the origin (0,0) to the end points determined by their marks.

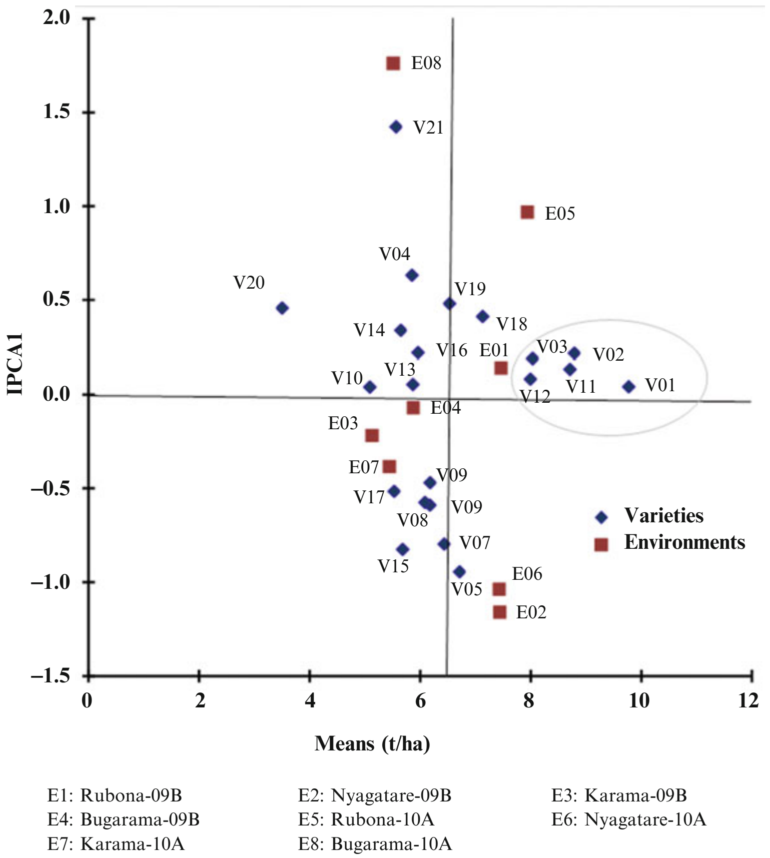
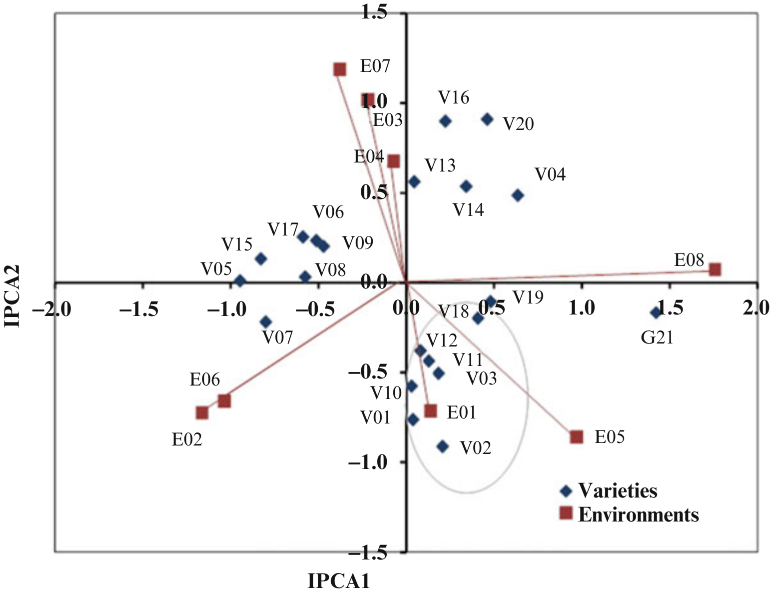


Fig. 14.1 Biplot of grain yield obtained by plotting the means (t/ha) against IPCA 1 [$(t/ha)^{0.5}$] for 21 crosses evaluated in eight environments in the mid-altitudes of Rwanda

Genotypes that appear close together exhibit similar behaviour whereas those that are far apart exhibit dissimilar behavior. An angle inferior to 90° or superior to 270° between a cultivar vector and an environment vector indicates a positive response of the genotype in the particular environment. A negative cultivar response is indicated by angle between 90° and 270° between a genotype vector and an environment vector (Crossa et al. 2002; Van Eeuwijk 2006.) The AMMI 2 biplot (Fig. 14.2) showed that the genotypes V11 (NYA1) and V12 (RUB 2) were the cultivars closest to the origin ($-0.05 <$ IPCA scores $< +0.05$) and hence were less sensitive to the changes of environment. Furthermore, as most of GEI pattern is within IPCA 1 (Van Eeuwijk 2006), the group of genotypes made by the cultivars V01 (CML442/CML440//CML445), V02 (CML312/CML202//CML445), V03 (CML144/CML159//CML182), V11 (NYA1), V12 (RUB2) and V10 (H513) was closer to the IPCA 1 axis (IPCA 1 scores <0.25) than to IPCA 2 (IPCA 2 scores <1.0) and therefore were relatively less sensitive to the changes of environments than other genotypes. This group of genotypes was particularly



E1: Rubona-09B E2: Nyagatare-09B E3: Karama-09B
E4: Bugarama-09B E5: Rubona-10A E6: Nyagatare-10A
E7: Karama-10A E8: Bugarama-10A

Fig. 14.2 Biplot of grain yield obtained by plotting IPCA 1 [(t/ha)$^{0.5}$] against IPCA 2 [(t/ha)0.5] for 21 genotypes evaluated in eight environments in the mid-altitudes of Rwanda

adapted to E01 (Rubona-2009 B) as the angle between genotype vectors and E01 vector was less than 30° (Fig. 14.2).

In AMMI 2 biplot, the environments with short spokes do not exert strong interactive forces; those with long spokes exert a strong interaction. All environments had long spokes and hence they exerted strong interactive forces on the genotypes. This was even stronger in harsh environments such as E08 (Bugarama-2010 A) and E07 (Karama-2010 A). Several studies have applied the AMMI 2 biplot to identify elite genotypes (Beyene et al. 2011) but it seems that it is the AMMI 1 biplot which is the most accurate for the identification of stable genotypes (Ntawuruhunga et al. 2001; Mwololo et al. 2009). In fact, it seems that the AMMI 1 biplot is suitable for stability across environments while AMMI 2 biplot is suitable for specific adaptability and the identification of suitable testing environments (Sadeghi et al. 2011; Hassanpanah 2011).

Conclusions

The AMMI analysis was used to describe the behaviour of 21 genotypes evaluated in eight environments (four sites × seasons) of the mid-altitudes of Rwanda. The four sites were representative of these heterogeneous environments. The AMMI

1 biplot was used to identify stable genotypes following particular attributes of the cultivars evaluated where it was found that drought tolerant and early maturing genotypes were the most stable across environments.

The AMMI 2 biplot was used to identify particular genotypes adapted to particular environments. Furthermore, it allowed an explanation of the behaviour of environments and how they exerted interactive forces on genotypes. Hence, the AMMI 1 biplot may be used to identify stable genotypes across environments while AMMI 2 biplot may be used to identify specific genotypes adapted to specific environments.

The mid-altitude environments of Rwanda are very heterogeneous and the four sites in this study might not have represented all the sub-environments. However, combining AMMI 1 biplot and AMMI 2 biplot in this study has allowed the identification of six elite cultivars: V01 (CML442/CML440//CML445), V02 (CML312/CML202//CML445), V03 (CML144/CML159//CML182), V11 (NYA1), V12 (RUB2), V13 (ECA-EPOP1) and V16 (KAR1) for the Rwandan mid-altitudes.

The hybrid variety CML442/CML440//CML with a grain yield of 9.8 t/ha is drought tolerant and stable across mid-altitude environments, therefore it is suitable for the semi-arid mid-altitudes of Rwanda, particularly the Karama site. The hybrid cultivar, CML312/CML202//CML445, combines resistance to MSV and TLB and is suitable for disease hot-spot environments, such as the Bugarama and Nyagatare sites. The hybrid variety, CML144/CML159//CML182, is a QPM and has about twice the levels of lysine and tryptophan in grain compared to non-QPM maize varieties (Krivanek et al. 2007; Sofi et al. 2009).

The OPV NYA1 (Pop Nyag) combines several useful traits including earliness, resistance to foliar disease, and tolerance to drought. It is high yielding and with a grain yield of 8.7 t/ha it surpasses most hybrid varieties (Table 14.1). It is likely to make an impact on maize grain production in the mid-altitudes of Rwanda. The OPV RUB2 (DTLWN1) has desirable grain quality, in addition to resistance to foliar diseases; ECA_POP1 and KAR1 are extra-early varieties and mature, on average, in 100 days after planting.

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Chapter 15

Determination of Appropriate Rate and Mode of Lime Application on Acid Soils of Western Kenya: Targeting Small Scale Farmers

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Abstract Western Kenya is experiencing declining food production as a result of increased soil acidity. Ongoing research in the region has demonstrated the potential of using agricultural lime, inorganic fertilizers, and Minjingu rock phosphates to address soil acidity problem while at the same time promoting food production. Despite this, the use of lime is still low among smallholder farmers due to lack of awareness on its effectiveness, and the best mode of application. This study aimed at comparing the performance of maize under three possible methods of lime application (spot, band, and broadcast methods) and four different rates of application (0, 2, 4, and 6 t/ha). The study was conducted in two target districts, Ugenya and Kakamega North of Western Kenya. The on-farm experiment was laid out in a 3 × 4 factorial in a randomized complete block design (RCBD) with four replications. All treatments received a blanket application of phosphorus (as TSP) and nitrogen (as CAN) at the rate of 26 kg/ha P and 75 kg/ha N. There was a significant increase in grain yield with the application of lime in both districts. Use of any of the methods did not gave significant differences in yield within the district but there was a significant difference between the lime rates used. In overall yield, the broadcast method gave the best results in the two district; whereas the best rate was using the 6 t/ha, this is because of high lime to soil contact. Also it was found that application of 6 t/ha of lime by the spot method lead to a significant decrease in

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yield compared to the other method using the same rate. This is attributed to overliming effects such as scorching of seedlings, effects on soil structure, and also element toxicities and deficiencies. This was not observed in North Kakamega because of the differences in lime requirements of the two districts. The labor costs per hectare required for the application of lime differed with method, the broadcast method was costly because a farmer was required to incorporate lime in the entire plot, while for the other methods, only the applied areas, i.e., band rows and hills are tilled. Therefore, despite the fact that the broadcast method is expensive in terms of lime application, this method gave the best yield response.

Keywords Soil acidity • Lime placement • Lime rates • Maize production

Introduction

In Kenya, acid soils cover about 13 % of total land area and are distributed widely in the croplands of central and western Kenya regions. Soil acidity affects over one million hectares of land under maize, legume, tea, and coffee crops putting over five million smallholder farmers at risk of crop failure (Kanyanjua et al. 2002; Gudu et al. 2007; Likeyo 2007). The problem of acidity has resulted from continuous use of nitrogenous fertilizers containing ammonium, leaching of basic cations, acid rains, continuous cropping, and removal or burning of crop remains, soil erosion, pollution, and inherent soil acidity from the parent material (Havlin et al. 2005). The types of acidic soils in Kenya are Acrisols, Andosols, Arenosols, Cambisols, Ferralsols, Gleysols, Luvisols, Nitisols, Vertisols, Fluvisols, and Regosols. These soils have pH(water) values ranging from 4.5 to 6.9 (WWW.kari.org/../feedview.php).

In Western Kenya region, soil acidity has resulted in low crop yield with average seasonal subsistence yields for the major food crops of maize, bean, and cowpea hardly exceeding 1 t/ha (Sanchez et al. 1996; Nekesa et al. 1999; Ayaga 2003; Okalebo et al. 2006) compared to 5–6 t/ha of maize per season obtained from research stations in the region, e.g., KARI Kakamega (Mbakaya et al. 2006). The impact of these poor yields is reflected in hunger at the household level often experienced 3 months after harvests.

The Kenya Agricultural Research Institute (KARI) Kakamega and Moi University have demonstrated the potential of using lime in combination with organic manure, inorganic fertilizers, and rock phosphates to address the problem of soil acidity and enhance soil fertility. Despite this, the use of lime is still low because of its unavailability, lack of awareness of its importance, and mode of application by farmers as well as weak extension services reaching the farmers. Another reason which is common globally as to why lime use is still neglected in the soil fertility program is because responses to lime are often not as visual as those obtained from nitrogen (N), phosphorus (P), and potassium (K), unless the soil is particularly acidic and, secondly, liming effects last for several years and the returns are not all realized in the first year (Mortvedt et al. 1999 and Terman and Engelstad 1976).

Best results are obtained from liming when there is close contact between the grains of lime and soil (Plaster 2003; Guantai et al. 2007). The broadcast method has been the most desirable method of lime application since all soil particles come in contact with lime particles (Troeh and Thompson 1993; Cook and Boyd 1987; Guantai et al. 2007). This is advisable because lime does not move far in a horizontal direction (Cook and Boyd 1987). However when the method is used when windy, a lot of lime is lost and no uniform distribution of lime is achieved.

On the other hand, row application of lime at the time of seeding legumes has been tried experimentally; the method is however difficult to manage because the farmer should also apply fertilizer. Thus to apply both materials, it is necessary to go over the land twice (Cook and Boyd 1987) which is expensive. Thus this method (row application) is suitable where it is desirable to keep the soil quite acidic for a single lime-loving crop in rotation. Spot application of lime may be helpful in changing the point where it is applied but not the entire field (Alubakar, Homa Lime Co. Personal communication). This is normally used on rented land where one needs high returns from the lime.

The study therefore aimed at using lime to address the problem of soil acidity in two districts in Western Kenya with different climatic conditions and soil type by assessing the economics of three possible modes of applications and four rates of lime, demonstrated under maize production. This will help in coming up with a suitable method and rate that small-scale farmers can use.

Methodology

On-farm experiments were conducted in four sites within Ugenya and North Kakamega districts. The two sites in Ugenya District were Sihay and North East Ugenya, formerly Siaya District. In North Kakamega, the two sites were Chimoroni and Chemuche. Table 15.1 presents the characteristics of the research sites.

Experimental Layout and Management

The study was conducted during the long rainy (LR) and short rainy (SR) seasons of 2010. The experiment was laid out in a 3 × 4 factorial in a randomized complete block design (RCBD) with four replications. Lime was applied in three methods

Table 15.1 Characteristics of sites in Ugenya and North Kakamega districts

Parameter	Ugenya District	North Kakamega
Coordinates	Latitude: 0° 03′ N Longitude: 34° 25′ E	Latitudes: 0° 26′ and 00° 52′ N Longitudes: 34° 52′ E
Altitude	1,140–1,400 m	1,300–1,900 m
Rainfall	Bimodal: 800–2,000 mm/year	Bimodal: 2,000 mm/year
Temperature	Maximum: 27–30 °C Minimum: 15–17 °C	Maximum: 25 °C Minimum: 8 °C
Soil type	Dystric Nitisols, Orthic Acrisols	Ferralo-Humic Acrisols

Jaetzold et al. (2005), Jaetzoldt and Schmidt (1983), and Republic of Kenya (2007)

Plate 15.1 Photos showing the three methods of lime application

(broadcast, band, and spot) as shown in Plate 15.1, with four lime rates (0, 2, 4, and 6 t/ha) but with phosphorus as TSP and nitrogen as CAN applied as blankets at the rate of 26 kg/ha P and 75 kg/ha N. The test crop used was maize (H 513) and the seeds were obtained from Kenya Seed Company. Each plot was 4.8 m × 4.5 m (21.6 m^2) and a space of 1 m was left between blocks and 0.5 m between plots. Seeds were planted at a spacing of 75 cm × 30 cm (recommendation by Kiiya et al. 2005). The other management practices like weeding and pest control were maintained equally across all treatments.

Measurements

Soil samples were collected before the application of treatments and thereafter at intervals of 1 month throughout the cropping season to assess changes in both selected physical and chemical properties. During lime application, the time spent per plot for carrying out the activity for each method was recorded. Harvesting of maize grains was done at physiological maturity of the crop indicated by the formation of a black layer at the tip of the grain. The size of the effective plot harvested after leaving out the guard rows was 4.2 m × 3 m (12.6 m^2). The weights of the ears/cobs from each effective area were taken and recorded. Then ten ear/cob samples (fresh weights measured and recorded) per effective plot were taken for air drying to a moisture content of about 13 % and threshed; the sample dry weights and threshed weights were taken to calculate the grain yield per plot.

Economic assessment involved timing the duration taken for each lime application method, maize grain yields (calculations shown above), and effects on soil fertility. Using the rate of 4 t/ha, the total time taken to apply and incorporate lime and fertilizers, and also making planting holes, seed placement, and covering was taken per site using each of the methods of lime applications. In this case, it was assumed that the time for carrying out the mentioned activities only differed with the method. While the rates of 2, 4, or 6 t/ha were the same across the methods, with 0 t/ha it was different since no lime was applied. However a farmer could incur costs when making planting holes, and placing and covering the seeds. A payment rate of KES. 35 per hour per casual laborer was used and extrapolated to get the cost per hectare. Calculations were done as follows:

$$Cost\ per\ site\ (per\ method) = (number\ of\ laborers \times time\ spend\ in\ minutes \times 7)/12$$

$$Cost\ (KES/ha) = (2500 \times cost\ per\ site)/21.6$$

Effects on soil fertility were determined by analysis of soil samples for physical and chemical properties. Soil samples collected in the field were first air-dried for at least 2 weeks in the greenhouse and subsequently the aggregates were broken by carefully pounding with a pestle and mortar. The samples were then passed through a 2-mm sieve to obtain fine earth for analysis for pH—1: 2.5 soils: water, available P (Olsen method), and particle size (hydrometer method). Further, the samples were passed through < 0.25 mm or 60 mesh (for analysis of organic carbon using the Walkley-Black method, and total nitrogen Kjeldahl method) (Okalebo et al. 2002).

Results

Initial Soil Characterization

The initial pH showed that the soils in both sites were acidic with pH below the minimum of 5.5 required by most plants (Table 15.2). As a result of the high acidity, essential plant elements in the soil, e.g., phosphorus and molybdenum are fixed by Aluminium (Al^{3+}), manganese (Mn^{2+}), and iron (Fe^{2+}) ions and this is why the available phosphorus was low. Phosphatic fertilizers applied to these soils are not utilized effectively by crops since they are fixed thus reducing returns from the

Table 15.2 Initial characterization of the study sites

Parameters	Siaya District	North Kakamega District
pH	4.95	4.68
Available P (mg/kg)	3.00	5.23
Organic C (g/kg)	24.0	29.0
Total N (g/kg)	1.4	2.5
C: N ratio	17: 1	12: 1
Textural class	Sandy clay loam	Sandy clay loam
Soil type	Orthic Acrisol	Ferralo humic Acrisol

crops planted on it; also these elements (Al, Mn, and Fe) displace basic cations such as calcium, magnesium, potassium, and sodium at the exchange sites (Wild 1993) causing deficiency of these essential elements.

Organic matter and clay content determine the buffering capacity of the soil; soils with high organic matter and clay content have a high buffering capacity and vice versa (Havlin et al. 2005). Therefore a high rate of lime should be applied on soil with a high organic matter and clay content to change the pH. Soil type is a determining factor to whether the soil becomes acidic or basic because of the parent material. The results justified the need for choosing lime as an appropriate amendment of soil acidity in the study sites.

Cost of Lime Application

The cost of applying lime varied with the method of application. The cost of application per hectare was KES 4707 (US\$52.30) for broadcast, KES 2624 (US\$29.15) for banding, and KES 3569 (US\$39.65) for spot application at the exchange rate of 1 US\$ = KES 90. The broadcast method was found to be expensive because lime was applied uniformly over the entire field and mixing with the soil means ploughing the whole field again. The spot application method involved mixing lime with soil using sticks or by hand so was time consuming. The band application method was cheaper compared to the other methods because of the area involved where lime is applied and it is possible to use a hand hoe while incorporating lime into the soil which was faster than by stick or hand.

Maize Grain Yield

From the results, a significant increase in maize grain yield was obtained by the application of lime in any of the rates compared to the control (no lime). There was also a significant difference ($P < 0.05$) in the application of lime by the broadcast method using 6 t/ha with band lime of 2 t/ha; a significant difference was also obtained from band lime of 6 t/ha with lime of 2 t/ha applied by the three methods

Table 15.3 Maize response to different rates and modes of lime application in North Kakamega District

Maize yields (t/ha)				
Method/Rate	Broadcast	Band	Spot	Mean
No lime	1.89	1.49	1.44	1.61
2 t/ha	2.46	2.09	2.54	2.36
4 t/ha	2.85	3.10	2.77	2.91
6 t/ha	2.98	3.14	2.78	2.97
Mean	2.55	2.46	2.38	2.46
SED (method * rate)	0.2908		LSD (method * rate)	0.5916
SED (method)	0.1454		LSD (method)	0.2958
SED (rate)	0.1679		LSD (rate)	0.3416
CV (%)	5.4			

Table 15.4 Maize response to different rates and modes of lime application in Ugenya District

Maize yields (t/ha)				
Method/Rate	Broadcast	Band	Spot	Mean
No lime	1.66	1.75	2.01	1.81
2 t/ha	3.92	4.03	3.92	3.96
4 t/ha	4.27	3.50	3.60	3.79
6 t/ha	4.36	4.28	3.34	3.99
Mean	3.55	3.39	3.22	3.39
SED (method * rate)	0.4434		LSD (method * rate)	0.9022
SED (method)	0.2217		LSD (method)	0.4511
SED (rate)	0.2560		LSD (rate)	0.5209
CV (%)	9.6			

(Table 15.3). The highest grain yield was obtained with the application of 6 t/ha of lime by the band method in North Kakamega district although it was not significantly different with 4 t/ha applied by the same method. The reason could be because there was high soil-lime contact within the root zone of the maize crop hence raising the soil pH (Guantai et al. 2007). As a result the activity of microorganisms in the soil is enhanced, and fixed phosphorus is also released so the plant can easily take in the elements by mass action through the roots. In addition, the element Ca is available for the crop and use of the method has a high residual effect compared with the other methods.

High grain yield was obtained by use of 6 t/ha of lime applied by broadcasting in Ugenya District. The reason is that the soils of Ugenya have a lower buffering capacity than those of North Kakamega District. Apart from reducing soil acidity, lime comes in contact with all the soil particles in the field thus controlling *Striga hermonthica* weed which is also a serious problem in Ugenya District. Grain yield in the treatments receiving spot application of lime at the rate of 6 t/ha were significantly different from yields for treatments receiving the same application rate but with broadcast method or for the treatments receiving 4 t/ha of lime applied by the broadcast method (Table 15.4). Application of high rates of lime by the spot method

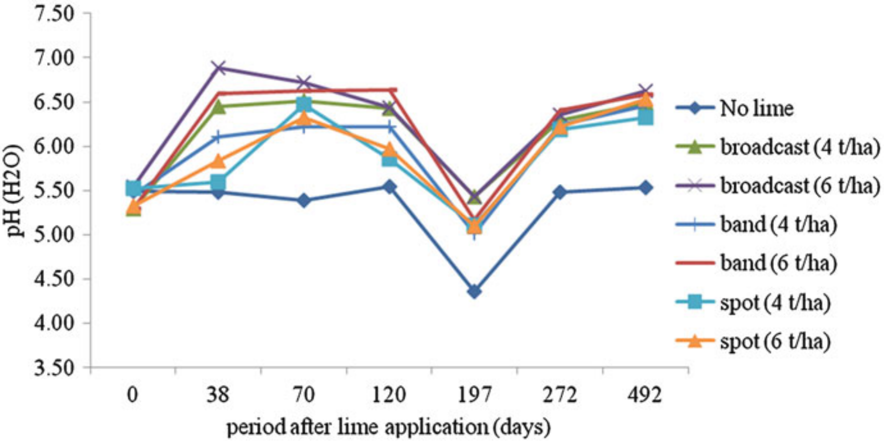

Fig. 15.1 Effects of liming rates and its placement on soil pH (H_2O) during two cropping seasons in Ugenya district

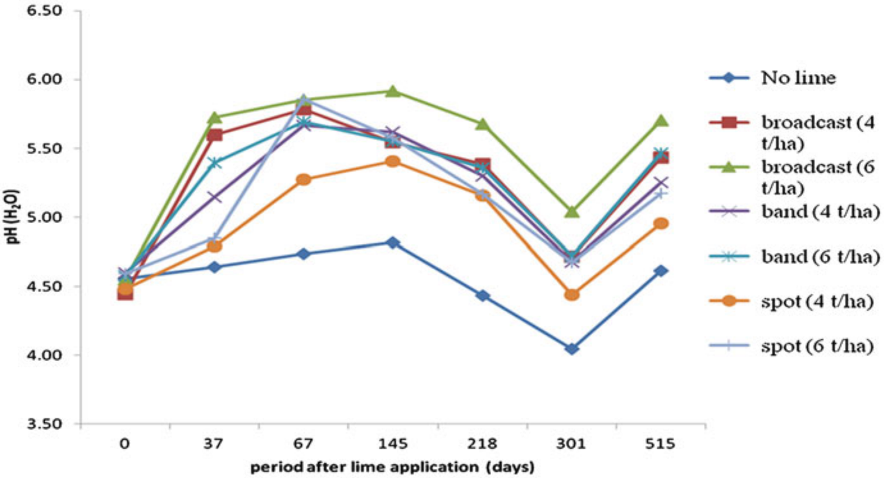

Fig. 15.2 Effects of liming rates and its placement on soil pH (H_2O) during two cropping seasons in North Kakamega district

might have resulted to an over-liming effect and wilting of plants was observed at the early stages of growth specifically with use of 6 t/ha by the spot method.

Changes in Soil pH

Figures 15.1 and 15.2 show changes in pH from the time of lime application and after three seasons of cropping with maize. When lime is applied and mixed thoroughly with soil, the soil pH was raised within a few weeks after liming. This was because calcium (from lime) very likely replaced Al^{3+} and H^{+} ions on the exchange sites by mass action so raising the percentage base saturation (Plaster 2003). The pH continued to increase very slowly until another tillage operation redistributes the lime particles, bringing them into contact with more acid soil, as a result pH drops and then it rises. The trends of graphs observed can also be attributed to the soil buffering capacity.

Conclusion

Lime is necessary for increasing soil pH in soils of Western Kenya to increase maize production. However for lime to work effectively on the soils of the target districts, current results suggest that lime should be applied by the broadcast method at the rate of 6 t/ha in both districts. The soils of the two target districts have a high buffering capacity and therefore high rates of 6 t/ha lime need to be applied for optimum results.

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Chapter 16

Assessment of Fertilizer Use Efficiency of Maize in the Weathered Soils of Walungu District, DR Congo

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Abstract Soil nutrient depletion is the constraint to productivity in South-Kivu province DR Congo. One of the reasons is the low capacity of the soil to retain water and nutrients for this reason, no response to fertilizer is observed. It could be necessary to combine fertilizer with manure of different qualities, in different rates and modes of application. Trials were conducted in two types of weathered soils of Walungu District: *kalongo,* red soils, and *civu,* black soils. Yield was affected by fertilizer use and the increase from NPK varied from 95 to 190 % compared with the similar treatment where NPK was not applied. Applying NPK to the control without organic matter (OM), led to an increase of 190 %. For OM alone, the improved manure applied in high doses and in pockets gave the highest yield within this category (1,350 kg/ha). The control without OM and fertilizer had the lowest yield (273 kg/ha). *civu* soils showed a higher yield than *kalongo* soils. Small-scale farmers can invest in fertilizer with local manure but it will be important to control quality to obtain a higher response to fertilizer.

Keywords Fertilizer efficiency • Weathered soil • Fertilizer use • Maize yield

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Introduction

Soils in sub-Saharan African countries are among those with the most severe shortages of nutrients (Smaling et al. 1997; Vanlauwe et al. 2001). According to the International Center for Soil Fertility and Agricultural Development (IFDC), Africa loses eight million tons of soil nutrients every year and more than 95 million ha of land are damaged to such an extent that productivity is meaningfully reduced (Henao and Baanante 2006). According to evaluations, at least 85 % of African countries experience nutrient losses of more than 30 kg ha^{-1} $year^{-1}$ and 40 % of the countries lose more than 60 kg of nutrients ha^{-1} $year^{-1}$ (Henao and Baanante 2006). It was shown that crops assimilate only 10–15 % of phosphorus (P); and 10–20 % of nitrogen (N) applied through fertilizers (African Fertilizer Summit 2006; Ogoke et al. 2006). This inefficiency in fertilizer use also discourages small-scale farmers from making investments in terms of inputs (Vanlauwe et al. 2001; Breman et al. 2001; African Fertilizer Summit 2006).

The major causes of declining soil fertility include the continuous extraction of nutrients by crops without any renewal measures and the low rate of use of mineral fertilizers (Vanlauwe and Giller 2006; Sanginga and Woomer 2009). Added to this is the supplementary effect that the low capacity of degraded soils to retain nutrients and water leads to losses of the minerals. In addition, the problem is linked with the galloping demography that entails an over-exploitation of the land for agricultural and various other needs (Smaling et al. 1997; Drechsel et al. 2001). In the above situation, Sanchez et al. (1997) concluded that the exhaustion of soil fertility in agricultural exploitations constitutes the main reason for the decrease in per capita food production in Africa.

This situation at continental level is reflected in the African Great Lakes region, particularly in the province of South-Kivu in the DR Congo. According to a survey conducted by the CATALIST project of IFDC, the balance of the soil nutrients in the region is the most negative in the world (IFDC 2009). According to this survey, nearly 100 kg ha^{-1} $year^{-1}$ of soil nutrients are lost by agricultural land. This problem is linked with a demographic pressure that is among the highest in sub-Saharan Africa. The region also has one of the lowest rates of fertilizer use, estimated at ca. 4 kg ha^{-1} compared with 110 kg ha^{-1} for the world (Henao and Baanante 2006; African Fertilizer Summit 2006). The region has extremely steep relief, making it highly susceptible to soil erosion by water (IFDC CATALIST 2009).

In addition to the problems of exhausted soils, fertility is very heterogeneous in this area and shows a high variability among farms, at both local and regional levels in Africa (Tittonell et al. 2005; Zingore et al. 2007). Variability in soil fertility can lead to differential responses to fertilizer and through proper local adaptation fertilizer can be targeted to the most responsive fields (Rowe et al. 2006; Vanlauwe et al. 2006; Tittonell et al. 2008). In acid soils, a response to fertilizer inputs is observed after the elimination of aluminum (Al) toxicity through corrective liming and the application of organic manure (Haynes 1984; The et al. 2006).

Strategies to reduce nutrient losses and improve the productivity of crops include the replenishment of soil fertility, increased use of inorganic fertilizers, and a more efficient recycling of biomass in the agricultural system. An integrated soil fertility management approach has been proposed. This calls for the use of improved germoplasm and mineral fertilizers, the good management of soil organic matter (OM) and local adaptations (Sanchez et al. 1997; Alley and Vanlauwe 2009) Thus, the use of OM combined with chemical fertilizer is instrumental in improving fertilizer efficiency because OM leads to an increase in the soil's capacity to retain water and nutrients, allows a progressive availability of nutrients to crops, and increases micronutrients uptake by roots (Sanginga and Woomer 2009).

Pypers et al. (2010) and Ellen Vandamme (2008) conducted several trials in weathered soil in Walungu District, DR Congo, and showed that the application of manure doubled grain yields in *civu* (fertile) and *kalongo* (poor) soils In the fertile soils, the combined application of manure and fertilizer tended to increase yields by 10 % above 1.5 t ha^{-1}, which farmers perceived as a very good bean crop. In the poor soils, the highest yields remained at 900 kg ha^{-1} in treatments with manure application, whether or not additional fertilizer was applied. Liming did not affect bean grain yields, independent of the fertility level and did not set off a response to fertilizer in the poor soils. Application of *Tithonia* leaf residues resulted in yield increases similar to those obtained after applying sole manure.

Unfortunately, the availability of OM in small-scale African farms is not guaranteed (Tittonell et al. 2005). Therefore, small quantities of manures are applied, especially in plots around the homesteads. That is the reason why a strategic use of OM, together with improvements in the mode of application, the quality and the rate of application, would compensate for low availability, thus increasing the manure production efficiency from various crop residues. The TSBF-CIAT always proposes the use of up to 5 t of manure ha^{-1} combined with microdoses of fertilizer (Pypers 2010).

This study complements ongoing research by CIALCA (Consortium for Improving Agricultural and Livelihoods in Central Africa) in the Lake Kivu region to evaluate the effect of manure, *Tithonia* and lime to increase the agronomic efficiency of fertilizer. Therefore, the objective of this work was to evaluate the fertilizer use efficiency of maize in two weathered soils in Walungu District and the effects of modes of manure application, quality and nutrient content.

Materials and Methods

Study Area

The experiments were conducted in Burhale in Walungu District, South-Kivu province, in the DR Congo. Burhale enjoys a moderate upland moist tropical climate. The dominant soils in Walungu are Ferralsols, according to the soil map of Belgian Congo and Ruanda-Urundi, Dorsale de Kivu, following the classification system of Institut National pour l'Etude Agronomique du Congo Belge (INEAC). Ferrasols are an intermediate phase between recently formed soils and highly weathered Ferralsols. This soil type is referred to as Dystric or Humic Nitisols (Deckers et al. 2003), according to the World Reference Base (FAO/UNESCO 1998). These soils contain a high proportion of carbon and a low base saturation rate; the pH is low, varying between 4.5 and 5.0; they are susceptible to erosion (Hecq 1961) and limiting for agriculture.

Table 16.1 Soil characteristics of the top soil (0–20 cm) in Burhale, DR Congo

			Civu (black soil)		*Kalongo* (red soil)	
Parameter	Unit	Range	Poor soil	Fertile soil	Poor soil	Fertile soil
Organic carbon (C)	mg/kg	15.7–48.8	28.5	35.9	19.7	24.5
Total nitrogen (N)	mg/kg	1.2–4.1	2.3	2.8	1.6	2.0
HCO_3^- extr. P	mg P/kg	0.98–22.5	4.21	5.47	4.26	4.73
PSI	mg P/kg	0.11–1.58	0.51	0.34	0.59	0.49
pH		3.96–5.54	4.53	4.23	4.73	4.37
K^+	Cmol+/kg	0.06–0.89	0.34	0.35	0.53	0.34
Mg^{2+}	Cmol+/kg	0.07–2.14	0.98	0.43	1.21	0.67
Ca^{2+}	Cmol+/kg	0.21–8.54	3.20	1.39	3.6	2.16
Al^{3+}	Cmol+/kg	0.02–4.17	1.20	2.38	0.91	1.53
Mn^{2+}	Cmol+/kg	0.06–0.86	0.47	0.26	0.24	0.26
ECEC	Cmol+/kg	3.70–10.5	6.10	4.83	6.44	4.96
Base saturation	%	15–99	67	45	82	60
Clay	%	64–82	68	69	66	70
Silt	%	13–24	19	21	22	18
Sandy	%	3–19	13	10	12	12

P sorption index P remaining in solution after addition of 625 mg P/kg, pH measured in 0.01 M $CaCl_2$

The experiments were installed at an altitude between 1,639 and 1,718 m above sea- level, and in latitudes between 2°41′44″S and 28°38′28″. This site was selected after a set of participatory rural appraisals and is representative in terms of biophysical characteristics (soils and growing season) and population density. In this site, farmers were asked to select fields with a history of recent cereal cultivation, some of which were relatively productive ("fertile") and others were relatively unproductive ("poor"). Farmers used their own knowledge and valuation techniques to distinguish fertility levels. Homestead plots and marshlands were excluded from this study. Selected fields had been cultivated during the past 10 seasons; some had been under cultivation for more than 50 years. The fields were located on slopes or plateaux, where legumes and maize are predominantly grown. Farmers also use a local soil classification system that distinguishes two major soil classes: *civu* (black soils) and *kalongo* (red soils). These two soil classes cover over 80 % of the land area in the territory. *Civu* soils occur more frequently, but not exclusively, in valleys and on lower slope positions; *kalongo* soils are more often found on the plateau and in the upper or mid-slope positions. Farmers generally value *civu* soils as being more fertile than *kalongo* soils, but distinguish fertility levels within each class. The local soil class was recorded for each of the fields presented by the farmers' groups. In Burhale, farmers presented only one fertile *civu* field and five poor *kalongo* fields, due to land constraints.

In the choice of the site, it was necessary to avoid banana plots and swamps as well as plots near the dwellings because those locations can influence soil fertility as a result of more frequent OM inputs. It was also necessary to avoid fallows of more than one season because most farmers do not practice fallow. The results of the chemical analysis of these soils are presented in Table 16.1.

Table 16.2 Treatment structure for experimental design

	Inorganic fertilizer		OM		
Treatment	Type	Mode of application	Quality	Mode of application	Dose (t/ha)
1A	–	–	–	–	–
2A	–	–	Local	Pockets	10
3A	–	–	Local	Pockets	20
4A	–	–	–	Pockets	10
5A	–	–	Improved	Pockets	20
6A	–	–	Improved	Spreading	20
1B	NPK	Pockets	–	–	–
2B	NPK	Pockets	Local	Pockets	10
3B	NPK	Pockets	Local	Pockets	20
4B	NPK	Pockets	Improved	Pockets	10
5B	NPK	Pockets	Improved	Pockets	20
6B	NPK	Pockets	Improved	Spreading	20

Methods

Experimental Design

Experiments were conducted with the hybrid maize variety WH403 from Kenya as the test crop. Two on-farm trials were set up in collaboration with farmers: six demonstration tests in season A 2009 and B 2010, and 30 adaptation trials at various sites (on different slopes) in season A 2010. Season A is the major rainy season; it extends from September to January and season B is the short rainy season that spreads from mid February to June. Table 16.2 shows the structure of treatments in the experimental design.

Five factors were studied to evaluate the OM quality with two variants (locally made manure produced by the farmers and the improved manure made in the National Agricultural Research Center, INERA). The dose was at two levels (low– 10 t/ha or high– 20 t/ha). The mode application was by spreading and in pockets. There were two variants in the supply of chemical fertilizer (present or absent). The fifth factor was soil type (*kalongo* or *civu*). Every treatment had two subplots, A and B. Subplot A received no NPK; subplots B received 17-17-17 NPK at a dose of 180 kg ha^{-1} (30 kg N, 30 kg P_2O_5, 30 kg K_2O). Every treatment consisted of 12 plots.

The dose (180 kg ha) for fertilizer was fixed according to results of trials previously conducted by CIALCA and was chosen according to the deficiency of P in the area. The OM was incorporated in the 15 cm top soils in treatment 6 and in pockets in treatments 2, 3, 4 and 5. To make the pockets, a hole was opened and chemical fertilizer was put in. Then some soil was spread over it before the seeds were sown; this was to minimize direct contact between seeds and inputs.

Subplots had five rows each measuring 4 m in length. . The area was therefore 3.75 × 4 m (15 m^2). The netplot was determined after excluding two external rows, one on each side, and 50 cm at every side of the interior lines. The effective harvested area measured 2.5 × 3.2 m (8 m^2). The plant spacing was 75 × 25 cm.

The variability associated with the locally produced OM was controlled by replicating the treatments six times in every experiment. The improved manure featured as follows in terms of contents: (C) 20.1 %, (N) 2.3 %, (P) 0.19 % (K) 2.4 % (Ca) 1.3 % (Mg) 0.50 % and (S) 0.31 %. The locally produced manure featured as follows in terms of contents: (C) 18.9 %, (N) 1.6 %, (K) 3.9, (P) 0.18 %, (Ca) 1.0 %, (Mg) 0.33 % and (S) 0.18 % on a dry matter (DM) basis.

Soil Sample Analysis

Soil pH was determined in an H_2O or 0.01 M $CaCl_2$ suspension at a soil: solution ratio of 1:2.5. Organic C and total N were determined by the Dumas combustion method, Vario Max CN (Americas Inc., Mt. Laurel, USA). Bicarbonate-extractable P and exchangeable K were determined in a modified Olson extract (0.5 M $NaHCO_3$ + 0.01 M EDTA at pH 8.5). Exchangeable Ca and Mg were determined in a 1 N KCl extract. Concentrations of bases were determined by atomic absorption spectrometry; P concentrations were determined using the method of Murphy and Riley (1962). Exchangeable acidity was determined by titration (Anderson and Ingram 1993). The effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable bases and acidity. Particle size analysis was determined using the hydrometer method after the OM was removed by oxidation with H_2O_2, dispersion using sodium hexametaphosphate, and the soil had been shaken overnight on a vertical shaker (Bouyoucos 1962).

Parameters Observed

Measurements were done mainly at final harvest where data on yield, agronomic efficiency (AE) were determined. The yield was obtained after the maize had been sun dried and shelled. The agronomic efficacy (AE) (refers to the proportion of yield increase as a result of application of 1 kg of N to maize) was estimated by the following formula.

$$AE = \frac{\mathrm{YTb} - \mathrm{YTa}}{\mathrm{N}}$$

Where:

YTb: Yield of treatment B, YTa Yield of treatment A, N: Quantity of N/ha applied and AE.

Apart from a demonstration trial for farmers, another 30 adaptation trials (conducted by farmers after selecting best treatment) were located on different slopes. Thus, fertilizer efficiency was measured along the slope.

Statistical Analysis

Data were analyzed within R-Statistic version 2.9-software. Analysis of variance separated to more than two criteria of classification in split-plot design was used. The post-ANOVA Duncan multiple range test for the least significant differences (LSD) was used to separate the means. Regression was used to compute the effects of slope on the AE.

Results

Yield

Figure 16.1 presents the results of the yield in the soils of Walungu District. Generally, higher yields were reported on *civu* than on *kalongo* soils.

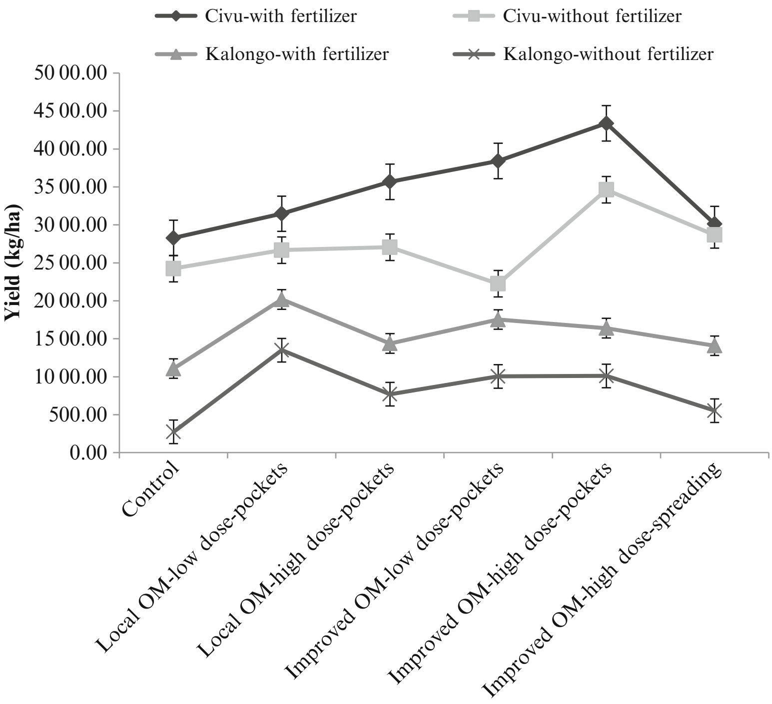

Fig. 16.1 Yield of different treatments across the two soil types in Burhale, DR Congo

Effects of the Quality of Organic Matter

Figure 16.1 shows that the quality of OM significantly influenced the yield of maize ($p = 0.001$). The OM from INERA (improved quality) displayed the best yield for treatments 4 and 5 where it was used. Also note that the local OM, treatments 2 and 3, gave a yield higher that of the control.

Effects of the OM Dose

The size of the OM dose applied highly significantly influenced the yield in grain ($p = 0.002$). The best yields were found in soils where high OM doses (20 t/ha) were applied (treatments 3 and 5); the control with no OM input gave the lowest yield.

Effects of the Modes of Application

The yield was significantly increased ($p = 0.002$) when the OM was applied in pockets rather than when it was spread. It proves that spreading wastes the OM because the crops are not able to use it efficiently. The application in pockets was advantageous as it permitted the elements to be released in the root zone.

Effects of Soil Types

The best yields were obtained in the *civu* (black soil) than in *kalongo* (red soil); the difference was very highly significant ($p < 0.0001$). The supply of NPK significantly increased the yield ($p < 0.0001$).

In the *kalongo* soils, the best treatment was where NPK was combined with improved OM in high doses and applied in pockets (2,018 kg/ha). This was followed by the treatment where NPK was combined with improved OM and applied in a low doses \and in pockets (1,753 kg/ha). The control gave the lowest yield (273 kg/ha).

The increase of the yield from NPK varied from 95 to 190 % compared with the similar treatment where NPK was not applied; applying NPK to the control without OM led to an increase of 190 %. Indeed, the inputs of OM do not release free mineral elements directly to the soil; the OM must first undergo the process of mineralization. The timing and speed of this process depend on the physical, chemical and biological properties of the soil. A sizable proportion of the minerals are otherwise immobilized by micro-organisms before being released to the soil (Vanlauwe et al. 2001).

For OM alone, the improved manure applied in high doses and in pockets (Treatment 5) gave the highest yield within this category (1,350 kg/ha). The control where no OM had been applied was last (273 kg/ha).

Table 16.3 Variation of the agronomic efficacy of maize in treatments where NPK was applied compared with treatments without NPK

Treatment	AE in *civu* soil	AE in *kalongo* soil
Control	19.73	27.25
Local OM-low dose-pockets	15.66	27.94
Local OM-high dose-pockets	28.17	20.54
Improved OM-low dose-pockets	46.33	24.48
Improved OM-high dose-pockets	28.58	21.81
Improved OM-high dose-pockets	24.76	21.86

The contribution of NPK had positive effects (Fig. 16.1) on the yield of maize in *civu* soil ($p < 0.0001$) Here, the best treatment was the one where NPK was combined with improved manure applied at high doses and applied in pockets (4,338 kg/ha). This was followed by the treatment where NPK was combined with improved manure applied in low doses and in pockets (3,842 kg/ha). The control where the NPK was brought in alone gave a low yield (1,985 kg/ha). The increase of the yield bound to NPK varied from 52 to 96 %.

For OM alone, improved manure applied in high doses and in pockets gave the highest yield in this category (3,463 kg/ha), followed by the treatment where local manure was applied in high doses and in pockets (2,706 kg/ha). The control without OM came last (2,424 kg/ha).

From a comparison of all treatments where the OM was applied in relation to the control, it is clear that, in the absence of NPK, the increases in the yield due to the different methods of applying OM varied from 10 to 43 %. The yield of maize increased more in *civu* soil than in *kalongo* soil (Fig. 16.1), even with NPK application.

Agronomic Efficiency of Maize

Table 16.3 presents the results on the AE of maize according to the various treatments.

Table 16.3 once again shows that the AE does not depend on the type of soil ($p = 0.3$) but rather on the quality of the OM and the method by which it is applied to the soil. In *civu* soil, the best AE was found in the treatment where the improved manure was applied in low doses and in pockets: 46.33 vs 15.66 (AE = index of yield increment/nutrient applied) when local manure is applied in a low dose. In the *kalongo* soil, an AE of 27.94 was observed in the treatment where local manure was applied in low doses. It sufficiently demonstrates that the existence of nutritional deficiency in the soils of Walungu. The agriculturist who adopts improved manure in high doses (20 t/ha) has the chance to benefit in terms of maize yields.

Agronomic Efficiency and Slope

Slope relatively influences the yield of maize and the efficiency of nutrients ($p = 0.027$). In *civu* soils, there was a significant increase in yield in relation to the slope but not in *kalongo* soils on lower slopes.. The equation for *civu* soil is $y = -350.53x + 5799.6$ ($R^2 = 0.0543$) and for *kalongo* soil it is $y = -167.75x + 5965.5$ ($R^2 = 0.0363$).

Discussion

Farmers understand soil quality. Soils considered poor gave lower yields and responded less well to inputs, than soils considered fertile. Mairura et al. (2007) showed that farmers in the central highlands of Kenya typically determine soil fertility based on the history of crop performance, soil colour and texture, tilth, and the presence of certain macro-fauna and weed species. Farmers in the area distinguished productive soils based on their darker colour, which corresponds with higher levels of organic C (Irungu et al. 1996). Because of its beneficial impact on important soil functions, the soil's organic C content is considered the most suitable indicator within a given soil class, positively related with soil fertility (Prudencio 1993); Islam and Weil 2000; Doran 2002. This is in contrast with our observations: soil analyses showed that farmers did not distinguish soil fertility based on soil OM levels. Average levels of organic C were high in all soils (>2 %), but were higher in poor soils than in fertile soils. The differences were not related to P availability, since all soils were equally P-deficient.

The results of this survey show that the incorporation of OM improves the efficiency of NPK in the growing of maize. The OM produced in the research centre and applied in pockets at a dose of 20 t/ha led to better yields than the locally made manure. Poor soils exhibit a low response to fertilizer application and therefore the AE will be weak; the management will consist in combining chemical fertilizers with OM. The supply of OM increases the AE, particularly the capacity to retain water and nutrients and provides a better synchronization of the release of nutrients according to the crop needs. It improves the health of the plants also through the improvement of soil biodiversity and carbon sequestration (Sanginga and Woomer 2009).

Improved manure offers a better opportunity to produce negative-charged organic acids sources. Findings (The et al. 2006) show that animal manure is more efficient than that based on leafy residues. In this work, the OM brought by the farmers was constituted either of animal dung or domestic garbage combined with a small quantity of dung. Mafongoya et al. (2006) showed that access to animal manure is a constraint for the small producers in sub-Saharan Africa.

Woperies et al. (2005) in a study in Togo reported that the application of fertilizers in fields around the dwellings benefits from the presence of more OM which increases the maize yield and the internal efficiency of nutrient inputs as well as the fertility of the soils. Vanlauwe et al. (2001) demonstrated in their turn that the direct effect of the contribution of OM results indeed from the absorption of N in the soil by the microbial biomass, which improves the synchronization of the intake and the demand for N by the crops and reduces the losses of N in the environment. In addition, they demonstrated the capacity of OM to improve the physical, chemical and biological properties of the soil and, therefore, the absorption of nutrients.

In general, OM influenced the efficiency of fertilizers on maize. Regarding the contribution of fertilizers, Pypers et al. (2010), who used other types of inputs, showed that fertilizers increase maize yields by 40 % in *kalongo* soils and by 100 % in *civu* soil in Walungu. These results are in agreement with those found in this work; they also came up to 90–190 % for maize.

Better yields were obtained in *civu* soils than in *kalongo* soils; the two soils were initially different in terms of fertility. From the results of soil analyses in 2008 (Ellen Vandamme), it is obvious that the difference is due to the content of P, though the deficiency appears in both soil types. For Vanlauwe and Giller (2006), P enhances the productivity of crops such as legumes. Another factor that differentiates the response by these soils is acidity and the level of exchangeable bases that act on the absorption of nutrients by plants. Tittonell et al. (2005) found yield differences in two soil types in Kenya due to available K and not to soil colour. In soils like *kalongo*, the effects of OM will not found in terms of a source of nutrients but rather in its functions of improving the capacity to retain water and nutrients. But in *civu* soils its function as a source of nutrients is relevant.

The current results are in agreement with those of Sanginga and Woomer (2009) who stated that the response to the chemical fertilizers depends on soil types. *kKalongo* soil does not ensure a good assimilation of nutrients, particularly of P that is immobilized, for example. For *civu* soil, the quantity of OM was initially already sufficient to ensure potential yields of maize. That explains the relatively weak efficiencies for some treatments. Thus, it is necessary to match the quantity of fertilizer with the composition of minerals and OM in the soil. Small-scale farmers can invest in fertilizer use with local manure but it will be important to control quality to obtain the higher response to fertilizer.

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Chapter 17

Improvement of Sweet potato (*Ipomoea batatas* (L.) Lam) Production with Fertilizer and Organic Inputs in Rwanda

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Abstract Sweet potato (*Ipomoea batatas* (L.) Lam) is one of the staple food crops for the Rwandese population with yields varying from 7 to 8 Mg/ha. Continuous land cultivation has resulted in nutrient depletion to an extent that further increase in productivity will require external nutrients. New high yielding sweet potato cultivars have been screened and tested for their response to fertilizer and lime and organic inputs in the main agroecological zones of Rwanda. Due to a period of institutional instability, some important results from 1980 to 1982 could not be published as yet. These data showed that each agroecological zone has its most adapted cultivar(s) and that the use of fertilizer/organic inputs improved yields. However, the high rates of fertilizer/organic inputs applied on the selected sweet potato cultivars had not led to the maximum yield. The effect of these inputs was highly influenced by crop husbandry and health, climatic conditions during the growth period, and soil properties of the experimental plots. Agroecological conditions are masking the cultivars' capacity to fully respond to fertilizer/organic inputs. It is recommended that types and rates of fertilizer/organic inputs be determined according to the types and levels of soil fertility.

Keywords Agroecological zones • Mineral fertilizers and organics • Research • Rwanda • Sweet potato yields

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Introduction

Three vital tuber crops, sweet potato (*Ipomoea batatas* (L.) Lam), Irish potato (*Solanum tuberosum L.*), and cassava (*Manihot esculenta* Crantz) are major staple food for the Rwandese population. Sweet potato root tubers are eaten boiled, roasted, and sometimes fried. In Rwanda, the leaves are not consumed but used together with the root tuber as fodder for animals.

Sweet potato is grown in all agroecological zones of Rwanda (Delepierre 1974; Verdoodt and Van Ranst 2003), but at altitudes lower than 2,100 m. An optimal equilibrium ratio of N, P, and K of 1.0/0.9/2.5 was proposed for Burundi, the neighboring country by Janssens and Ntimpirangeza (1985). In 1979, sweet potato was the most expansively grown (1,060 km^2) among the root and tuber crops and with an average yield of between 7 and 8 Mg/ha of root tubers (Janssens 1980; MINAGRI 1989). In 1985, the yield was still unchanged but the area cropped had increased to 1,500 km^2 (FAO 1996). The importance of sweet potato for the Rwandese and its relatively low yield were two reasons for research to develop cultivars that were more productive and adapted to the country's ecological conditions. A breeding program using "Polycross seed field with variable composition" generated precocious, productive, and well-adapted cultivars (ISAR 1980). In order to achieve optimal performance, cultivation of these cultivars has to be accompanied with proper crop husbandry. Therefore, two experiments for validating simultaneously the potential of created cultivars and various rates of fertilizer and organic inputs were established in 1980–1981 and 1981–1982 on various sites representing all Rwanda agroecological zones. These datasets remained unexploited at the University of Bonn. In view of conveying the important results to researchers currently working in the area of sweet potato, this paper presents the field results obtained throughout Rwanda and shows some guidelines for further improving sweet potato production. Nutrient recovery was estimated to highlight possible nutrient imbalances, particularly among the treatments combining minerals with organic inputs.

Material and Methods

During two seasons (October 1980 to May 1981 and October 1981 to April 1982) and in 18 sites, 17 sweet potato cultivars were tested for their production potential and for their response to 16 types of fertilizer and organic inputs (Tables 17.1 and 17.2). Fertilizers were ammonium sulphate ($(NH_4)_2SO_4$; 21 % N), urea (45 % N), triple super phosphate (9 % P), and potassium sulphate (K_2SO_4; 42 % K). Lime was used as an amendment (Rutunga and Neel 2006; Rutunga et al. 1998). Organic inputs were farm yard manure, the nutrient content of which was calculated in accordance with the estimates of the reference manure analyzed at the central station of Rubona (Rutunga et al. 1998) and mulch for which nutrient content was not determined.

Table 17.1 Fertilizer/organic treatments and cultivars tested in 1980–1981 and in 1981–1982

Year 1		Year 2	
Nutrient content (N-P-K, kg/ha)[a]	Cultivars	Nutrient content (N-P-K, kg/ha)	Cultivars
T1: Control	1. Rusenya	T1 : Control	1. Rusenya
T2: 210-88-539	2. Caroline Lee	T2 : 210-88-539	2. Caroline Lee
T3: 100-44-83	3. Nsenyakaniga	T4 : 230-88-539	4. Nyiramujuna
T4: 230-88-539	4. Nyiramujuna	T6 : 210-88-497	5. Nyiranjyojyo
T5: 210-88-539, 2 Mg lime/ha	5. Nyiranjyojyo	T7 : 250-88-580	6. Bukarasa
T6: 210-88-497	6. Bukarasa	T8 : 145-38-296	8. Rutambira
	7. Cordes rouges	T9 : 250-110-580	10. Cordes vertes
	8. Rutambira	T10: 230-88-539	11. Anne Marie
	9. D. Virosky 16	T11: 210-88-497, mulch	12. TIS 2544
		T12: 210-88-580	13. Caroline Lee 1666
		T13: 125-38-255	14. Nyiramujuna 352
		T14: mulch	15. Caroline Lee 1668
		T15: 50-44-83	16. Nyiransase
		T16: 210-88-580, 2 Mg lime/ha	17. Nsasagatebo

[a] Fertilizer and organic inputs: *T1* no fertilizers and no organic inputs, *T2* 42 kg K and 35 Mg fresh manure/ha, *T3* mineral fertilizer N-P-K, *T4* 20 kg N, 42 kg K and 35 Mg fresh manure/ha, *T5* 42 kg K, 35 Mg fresh manure, 2 Mg lime/ha, *T6* 35 Mg fresh manure/ha, *T7* 40 kg N, 83 kg K and 35 Mg fresh manure/ha, *T8* 40 kg N, 83 kg K and 15 Mg fresh manure ha^{-1}, *T9* 40 kg N, 22 kg P, 83 kg K and 35 Mg fresh manure ha^{-1}, *T10* 20 kg N, 42 kg K and 35 Mg fresh manure/ha, *T11* 35 Mg fresh manure/ha and mulch, *T12* 83 kg K and 35 Mg fresh manure/ha, *T13* 20 kg N, 42 kg K and 15 Mg fresh manure/ha, *T14* mulch, *T15* mineral fertilizer N-P-K, *T16* 83 kg K, 35 Mg fresh manure, 2 Mg lime/ha. The mineral fertilizers were: urea as a source of nitrogen (except for treatments T3 and T15 where the Nitrogen supply was equally divided between $(NH4)_2SO_4$ and urea), K_2SO_4 for potash, and triple superphosphate for phosphorus

The experiments were established in the fields of farmers, schools, nutritional centers or development projects spread in all the country. Soils and agroecological data for all sites and for both years are listed in Tables 17.1–17.2 and Fig. 17.1. Lime was spread after the first digging and incorporated in the 0–15 cm soil depth 15 days before soil levelling. In each site the experiment was laid as a randomized split plot with two replicates. The main plot was for fertilizer and organic inputs and the subplot was for cultivars (one ridge/cultivar). For each season and each site, there were six main treatments and five sub-treatments corresponding to five tested cultivars considered as the most adapted to the area. The main plots were 12 m^2, i.e., 3 m × 4 m and were separated by a 1-m path.

In the first year (1980–1981), nitrogen was supplied in the ratio of urea N/ammonium N at 1.0:8.6 for T3 and as urea alone for T4. Both treatments received the first portion of N (89.6 kg N.h^1 and 17.9 kg/N ha, respectively) at planting, and the second portion (10.4 N/ha and 2.1 kg/N ha, respectively) as a foliar aspersion of

Table 17.2 Agroecological data for the 18 experimental sites and best fertilizer × clone combinations

						Best fertilizer × clone combination 2nd year				
Agroecological zone	Site	Altitude (masl)	Climate, Köppen[a]	Rain (mm/year)	Soils[b]	Fertilizer	Clone	Mg/ha	pH $_{(water)}$	Saturation %
East savanna	Nyagatare	1,400	Aw3-4	900	Ferralsols	14	Carolne Lee	29.2	5.4	51
	Nyagahanga	1,450	Aw3	950	Cambisols	6	Nyiramujuna	14.0		
Eastern plateau	Zaza	1,500	Aw3	1,050	Ferralsols	4	Rusenya	44.0		
Bugesera	Karama	1,400	Aw3-4	1,000	Ferralsols	4	Nyiranjyoyo	8.8	4.8	48
	Nyamata	1,450	Aw3-4	1,000	Ferralsols	7	Nyiranjyoyo	28.0		
Mayaga	Mututu	1,500	Aw3	1,100	Cambisols	11	Anne-Marie	21.2		
	Ntongwe	1,550	Aw3	1,100	Cambisols	7	Caroline Lee	42.0		
Granitic zone	Byimana	1,650	Aw3	1,150	Nitisols	8	Rusenya	26.0		
	Rugobagoba	1,600	Aw3	1,150	Nitisols	4	Rusenya	24.8		
Central plateau	Rubona	1,700	Aw3	1,200	Nitisols	9	Rusenya	42.0	4.9	31
	Rwaniro	1,650	Aw3	1,200	Nitisols				5.0	35
	Ndora	1,650	Aw3	1,200	Nitisols					
Zaire-nil crest	Mata	1,650	Aw2	1,300	Alisols	4	Nyiranjyojyo	6.0	4.4	6
	Kavumu	1,850	Cw2	1,300	Alisols	6		7.2	4.3	11
					Acrisols		Nyiransase			
	Giciye	>1,900	Cw2	1,350						
Volcano lands	Ruhengeri	1,850	Cw2	>1,400	Andosols	7	Rusenya	24.6	5.4	33
Buberuka highland	Rwerere	>1,900	Cw1-2	>1,400	Acrisols	4	Anne-Marie	34.6	4.7	12
	Ndiza	>1,900	Cw1-2	>1,400	Alisols	8	Caroline Lee	14.8		

[a] ILACO (1985)

[b] Driessen et al. (2001)

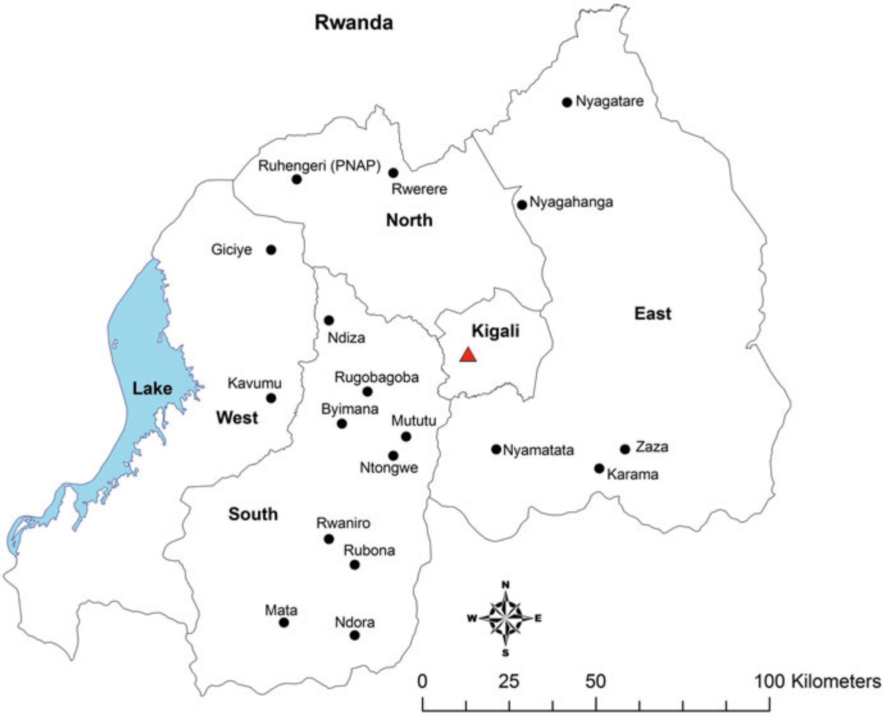

Fig. 17.1 Locations of the sweet potato cultivars and fertilizer inputs experiments in Rwanda

urea solution (5 g urea/L water) one month after planting. Other fertilizer and organic inputs were all spread and incorporated in soils at planting, before ridging as recommended by de Paes Camergo and Freire (1962).

In the second year (1981–1982), all mineral fertilizers were applied with half at planting and the remainder at 2.5 months after planting. Two young and healthy vines, 30 cm long were planted on both sides of the ridge, i.e., two vines per hole. Each ridge had a basal diameter of 40 cm and two vine-holes were 30 cm apart. There were 166,666 vines/ha, i.e., 60 holes per clone and per main plot. Weeding that is not practised in all Rwanda zones, was done when needed from one month after planting. Diseases and pests were observed but not controlled during the growing period.

Harvest in the first year (1980–1981) was done on 1 m^2 per clone and per replicate, from 8 to 16 May 1981, i.e., 6 months after planting. In the second year, the harvest was done in April 1982. Fresh root tubers harvested from each subplot were counted and weighed, vines were also weighed. For the first year, data were subjected to the analyses of variance and multiple regression, considering Rusenya and Nyiranjyojyo cultivars and all sites together. The same statistical analyses were then performed for sites in the same agroecological zone having the same sweet potato cultivars, and finally for each site with all its cultivars.

For the second year, the same hierarchy was applied for statistical evaluation. Cultivars present in all sites were Rusenya and Caroline Lee. Harvest Index (HI) is defined as the ratio of fresh root tubers to fresh total biomass. The proportion of nutrients recovered by biomass at harvest from applied fertilizers and organic inputs was calculated for all the sites where these inputs produced a significant response (Tables 17.2, 17.3, and 17.4; aboveground biomass not reported here) as per the relation:

$$\%\ nutrient\ recovered = 100 \times \frac{(B - A)}{C}$$

where B is the amount of nutrient exported by the biomass harvested from a fertilized plot, A is the amount of nutrient exported by the biomass harvested from the control plot, and C is the amount of nutrient in the fertilizer or/and organic treatment. This recovery rate is a rough approximation, as the nutrient content in harvest products is considered similar for all treatments. And yet, this nutrient content differs as a plant is grown in conditions of maximal dilution (e.g., in products from plots with low available nutrients or the control) or of maximal concentration (e.g., in products from plots with optimal or maximal available nutrients). Also change may be related to cultivars, measured plant portion, age at sampling period, and dry matter content in fresh harvest materials.

Results and Discussion

Growth Observations

Overall yield in the first season was only half that of season two (Tables 17.3 and 17.4). The percentage of vine regrowth in the first year was high, more than 70 % in general. The low percentage of vine regrowth (less than 70 %) with Nyiranjyojyo in Nyamata and Zaza and with Caroline Lee in Nyamata could not be explained. The regrowth rate of sweet potato progressively improved with increase in altitude from 1,400 m to 2,000 m. High altitudes are characterized by cool climate that reduces the vine transpiration rate in favor of regrowth. There were very few pest and disease attacks in the first year. However, vine regrowth in the second year (1981–1982) was poor. Indeed, virus attacks were observed on all cultivars in Rugobagoba, PNAP Ruhengeri, and Mata, and on Anne Marie cultivar in Mututu and Ntongwe. Weevil (*Cylas formicarius* Fabricius) was severe in Rugobagoba, Mututu, Ntongwe, and Nyagahanga. Localized caterpillar attacks were observed in Ndiza while field mice (Muridae) and moles were a major problem in PNAP. Nyiramujuna was the least affected cultivar by viruses, caterpillars, and weevils that are the major constraints for sweet potato production in tropical areas (Hahn 1980). Nyagahanga site (year 2) was near a eucalyptus plantation that could have generated allelopatic effects (shade, toxic secretions, water or/and nutrient competition) (Rice 1984) unfavorable to sweet potato production.

Table 17.3 Yield of root tubers (Mg/ha) in eight experimental sites 1980–1981

Treatments	Mean across sites	Nyagahanga	Karama	Rwaniro	Ndora	Mata	Kavumu	PNAP-Ruhengeri	Rwerere
T1. Control	4.6	4.1	3.7	4.1	7.3	4.1	4.0	4.3	2.8
T2. 210-88-539	5.6	9.0	4.2	4.2	6.5	5.4	6.7	7.1	3.8
T3. 100-44-83	5.0	6.3	3.6	3.5	5.2	5.1	2.9	7.4	2.4
T4. 230-88-539	6.5	9.4	3.5	7.1	6.2	6.4	7.1	6.0	3.0
T5. 210-88-539, and 2000 lime	6.1	5.3	4.8	3.6	3.3	8.6	7.7	6.1	3.7
T6. 210-88-497	5.3	7.4	5.2	5.9	3.3	5.4	5.3	7.0	3.0
LSD 0.05	1.0	1.8	1.8	1.8	1.8	1.8	1.8	1.9	1.0
P[a] treatment × sites	0.07	–	–	–		–	–	–	–
LSD 0.05	0.5	1.6	1.6	1.7	1.7	1.7	1.7	1.8	0.9
P cultivars × sites	0.00	–	–	–	–	–	–	–	–
P cultivars × treatments	0.41	–	–	–	–	–	–	0.9	0.8
P sites	0.098	–	–	–	–	–	–	–	–
General average	5.5	6.9	4.2	4.8	5.3	5.8	5.6	6.3	3.1
Best Cultivar	Rusenya	Car. Lee	Rusenya	Rusenya	C.rg.	Rusen	Rusenya	Rusenya	Ru'bira
	7.1	16.0	6.8	7.4	9.0	9.3	8.9	8.1	5.8

[a] P means probability of error

Table 17.4 Yield of root tubers (Mg/ha) per site, fertilizer/organic treatment and per clone 1981–1882

Altitude	<1,500 m			1,500–1,800 m				>1,800 m		
Treatments	Nyagatare	Zaza	Nyamata	Mututu	Rugobagoba	Rubona	Mata	Ruh.geri	Rwerere	Average
T1. Control	10.9	12.7	7.9	3.6	8.3	12.2	0.3	5.0	1.1	6.9
T4. 230-88-539	16.3	21.2	10.0	1.9	15.3	18.0	1.1	12.6	9.0	11.7
T6. 210-88-497	18.1	15.0	9.5	5.0	13.5	20.0	2.4	9.5	11.5	11.6
T7. 250-88-580	15.0	16.6	14.7	4.3	12.1	18.6	5.2	7.3	6.9	11.2
T8. 145-38-296	13.5	14.9	14.2	4.0	10.4	20.0	3.4	11.0	10.0	11.3
Tx. Variable[a]	22.9	18.6	13.1	12	14.6	21.6	1.5	11.2	7.5	13.7
LSD 0.05	3.8	4.3	3.7	2.5	2.2	2.0	1.9	3.6	3.5	
[a]Tx variable	*T14*	*T13*	*T12*	*T11*	*T10*	*T9*	*T16*	*T15*	*T2*	
LSD 0.05	3.5	3.9	3.5	2.2	2.0	4.5	1.7	3.3	3.3	
General average	16.1	15.7	11.6	5.1	12.3	18.4	2.3	9.4	7.7	11.0
Best Cultivar	Car. Lee	Rusen	Car. Lee	Anne-M.	Rusenya	Car.Lee	N'jyo	Rusenya	Ru'bira	
	22.2	27.8	16.2	6.7	14.6	27.8	3.7	15.8	19.7	
Harvest Index	0.58	0.56	0.49	0.33	0.50	0.39	0.19	0.38	0.23	0.29

[a] For the meaning of Tx variable, see footnote of Table 17.1

Site Effects

The most productive sites were found in Nyagatare and Zaza below 1,500 m, and in Rubona at mid-elevation during the second season (Table 17.4). In some sites with moderate acid soils and enough rainfall (e.g., Ndora and Nyagahanga in the 2nd year), below expectation nutrient response was recorded. Ndora has clayey soils and is situated in a concavity, which may have favored temporary but regular stagnation of the rainfall water therefore reducing root tuber production. Sweet potato gives high yields in good, well-drained soils with a clotted non-compact structure (ISABU 1984; Janssens and Ntimpirangeza 1985).

Acid Soils

In acid soils with high Al^{3+} content (Alisols of Mata, Kavumu, and Ndiza, Acrisols of Giciye and Rwerere), liming should have been beneficial through alleviating Al toxicity and making P fixed in soils available to sweet potato (Sanchez and Uehara 1980). Former experiments with fertilizer and organic inputs in Rwanda have shown the importance of liming and/or applying large amount of manure in the very acidic soils (Neel 1986; Rutunga and Neel 2006) and the effect of N application in soils with pH_{water} between 5.2 and 6.0 (ISAR 1980–1984). The low effect of liming observed in this study cannot be explained as far as liming was supplemented by manure for eliminating any eventual nutrient imbalance (Mg, micronutrient deficiency, P fixation).

Low Soil Moisture

Some sites in areas lower than 1,500 masl and in Mayaga had low moisture in soils during the sweet potato-growth period and the consequence was that nutrients from manure were not totally available or used by the crop. Dried organic matter slowly and less easily dampens again (Janssen 2000). Finally, variability in nutrient content of manure should not be ignored, and perhaps nutrients in our treatments were not as high as estimated (Rutunga et al. 1998; Landa 1983; Hartermink 2006).

Fertilizer Effects and Their Interactions with Sites

In the first year, fertilizer input treatments increased sweet potato production by 25 % relative to the control (T1), except in Ndora (Table 17.3). In general, the yield of root tubers was high where there were many vines, the root tubers of average weight, and the root tuber numbers high (data not presented). In the second year, the effect of fertilizer/organic treatments was positively significant by more than 66 % in nine out of 15 sites (Table 17.4). Moreover, the average Tx variable treatment, i.e., the optimal a priori treatment chosen specifically for each site, was the best overall treatment. It indicates that non-factorial guesses can be informative.

The effect of fertilizer and organic inputs was significant, but almost at the same level for all nutrient input treatments. The explanation may be that N, P, and K nutrient content in the treatments was almost similar, except for fertilizer N-P-K in the first year and treatment T8 in the second year. In the organic treatments, either pure like T6 and T11 or in combination with mineral fertilizers, N (210–250 kg/ha) and K (497–580 kg/ha) contents were high while P level was low and uniform (88 kg/ha). One should note that two of the organic treatments, T8 and T15, had their organic supply reduced by half. However, availability and efficiency of these nutrient inputs also varied according to the material source, i.e., as farmyard manure, mulch, lime, or fertilizer NPK. Manure that provides various nutrients during its humification and improves soil physical properties (Janssen 2000) had only moderately increased the yield of root tubers: the production rarely doubled although most treatments did contain organic inputs. Under Rwandan conditions, Rutunga and Neel (2006) estimated that 10–40 % of manure nutrients are generally available for a seasonal crop where manure is applied, the remaining serving as a residual effect or simply being lost through various processes in soils. Immature and/or low quality manure may immobilize its nutrients and those from soils for a certain period, leading to mineral deficiency for crops to which it is applied. The period of immobilization is as long (less than 3 months) as soils contain inadequate moisture, compounded with relatively fresh temperatures and acid pH, appropriate for limited microbial activity and slow humification (Kabba and Aulakh 2004).

Nitrogen Excess and Harvest Index

Furthermore, Nitrogen excess that favors aerial biomass production to the detriment of root tubers cannot explain this moderate response to organic inputs, since the correlation with root tubers and vines or soil covering rate was positive everywhere (not reported) and the harvest index (HI) comprised between 0.1 and 0.7 in all input treatments (Table 17.2). High HI indices were recorded in the drier and lower sites as well as in Ruhengeri where nutrient supply was adequate. The combination of low HI with high total biomass offers an opportunity for feeding animals with abundant vines as, e.g., in Rwerere, Giciye, and Mata or for less nutrient removal when left in the field as crop residues. On the other hand, high HI values may offer high root yields but little vine production and hence, reduced ground cover. The latter restriction has environmental negative implications.

Fertilizer × Site Interactions

Sweet potato response to N, P, and K nutrients was dependent on soil and climatic conditions of sites: no effect was evident where there was a water deficit (e.g., Karama) or in very acid soils with high Al^{3+} content (e.g., Kavumu, Rwaniro, Rwerere), and there was a significant effect where only N or P or K were deficient (e.g., Ruhengeri, Nyagahanga in the 1st year). Efficiency of N, P, and K application to a crop is optimal when other constraints related to soil, climate, and crop husbandry are eliminated (Janssen et al. 1990; Neel 1986). Root tuber production in the control plots was never null, even in the sites with critical constraints (very poor soils, drought etc.). This shows that sweet potato is able to extract some nutrients from very poor soils for making a certain level of yield on fields where other crops with high nutrient requirements such as legumes and cereals fail to produce anything. On the other hand, there was no single site where optimal or maximal yield was attained under no input (control) situations showing that in Rwanda an opportunity for increasing sweet potato production through agricultural intensification techniques is still available.

Mulching

High root tuber yield was recorded in Mututu, Ntongwe, and Nyagatare with mulching (T11 and T14 in Table 17.4). Mulch cover stores soil water for the crop by reducing the run-off and evaporation (Lal 1990; Neel 1986). In Nyagatare, T14, i.e., sole mulch, was enough to surpass all other fertilizer treatments. In the no-mulched sites under dry spells, the lower yield of the plots with manure as compared to that of the control revealed the negative effect of organic matter incorporated in soils with low moisture (e.g., Ndora, 1st year).

Clonal Effects and Interactions with Sites and Fertilizers

Cultivars Rusenya, Caroline Lee, and Nyiranjyoijo have largest adaptability to different environments (Tables 17.2, 17.3, and 17.4). Significant cultivars × site differences were observed and this could be due to the soil and climatic variability recorded in Rwanda (Birasa et al. 1992; Djimde et al. 1988; van Minnenbruggen 1972), which influenced the production potential of sweet potato. Rusenya cultivar had the highest yields except in Nyagahanga where it was out-yielded by Caroline Lee, in Ndora by Cordes Rouges, and in Rwerere by Rutambira. Rutambira cultivar was best at an altitude of 2,000 m (Rwerere), Rusenya at altitudes between 1,550 and 1,900 m, and Caroline Lee in zones of altitudes less than 1,500 m (Nyagatare, Karama). Anne-Marie and Nyitanjyojo adapted to marginal sites as in Mututu and Mata.

Yield of root tubers showed that all cultivars significantly responded to fertilizer and organic inputs. Moreover, cultivar × nutrient input interactions were also significant at $P < 0.05$, suggesting that the on-going sweet potato breeding program at ISAR incorporated enough genetic variation to respond to fertilizers, organics, and different environments. There were one or more cultivars and one or more

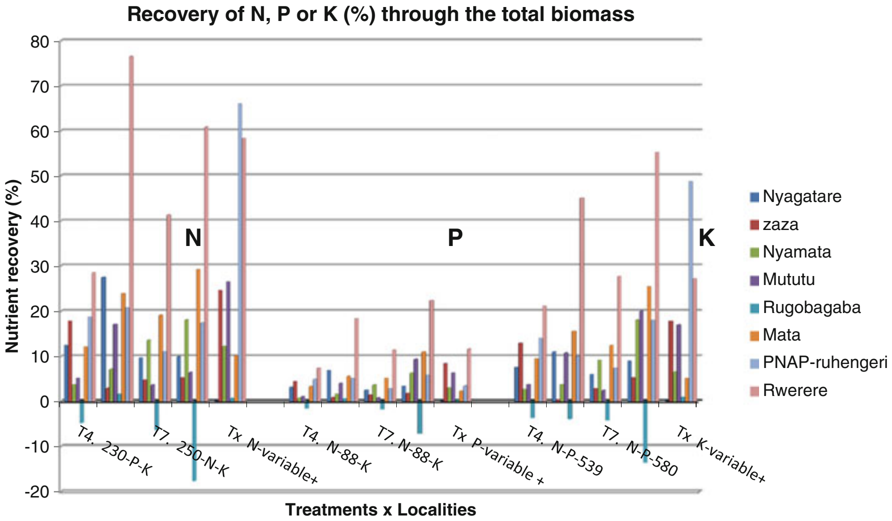

Fig. 17.2 Nutrients taken up by both root tubers and vines in (%) from nutrient inputs applied in various fertilizer treatments

fertilizer/organic inputs adapted to each experimental site (interactions of cultivars × sites, and that of nutrient inputs × sites significant at $P < 0.01$). Hence, for each site we do need to identify specific nutrient × cultivar combinations. A point in case is the outstanding performance of clone Rutambira in Rwerere when fertilized with (T4), i.e., a farmyard manure supplemented with mineral nitrogen and potash which improved performance under cold stress conditions.

Recovery Rate

The recovery rate of N, P, and K from fertilizers/organics by sweet potato crop was influenced by sites, fertilizer/organic treatments, by type of nutrient and by amount of below and aboveground products (see chosen treatments in Fig. 17.2). In general, the recovery is high in zones of altitude >1,500 m (Mata, PNAP, and Rwerere). In Rugobagoba (in green), severe virus and weevil attacks greatly reduced vine development, particularly in the fertilized treatments, resulting in negative recovery estimates (Fig. 17.2).

Experimental results revealed that the nutrient recovery from inputs varied, depending on crop protection level, water availability during the growth period, input adequacy to soil conditions, crop husbandry, and aboveground biomass (Fig. 17.2). In zones of altitude <1,500 masl and prone to drought, nutrient recovery was low; no nutrient recovery was seen in Rugobagoba and other sites severely infected with diseases and pests; it was high in zones of altitudes between

1,500 and 2,100 masl (Mata, PNAP, Rwerere) where water was sufficient. During the first season of the experiment, N-P-K fertilizer (T3) was the leading treatment in PNAP where soils are not highly degraded (Table 17.2) and nutrients from fertilizer were more easily available than those from manure that slowly decomposed in volcanic soils under a different climate (Broadbent et al. 1964; Janssen 2000). The same positive effect was observed in the second season (T15 = T4 and T8).

Large amounts of N, P, and K nutrients were recovered in aerial biomass for the sites >1,800 masl. This was due to the harvesting at 6 months, which was too early for photosynthesis product migration and for the complete development of tubers. In C_w climate of Rwanda and Burundi, sweet potato cultivars used in this study require eight months for reaching their physiological maturity (Janssens and Ntimpirangeza 1985). Also, high humidity during the sweet potato growth period or humid zones (e.g., zones above 1,800 masl.) favor vine production to the detriment of tubers (Hartemink et al. 2000). In this study, a high rate of fertilizer and organic inputs seemed to have been applied (Table 17.1), surpassing most nutrient export estimates. Indeed, a yield of 10 Mg tubers and 15 Mg vines extracted from soils 83 kg N, 19 kg P, and 146 kg K (Fig. 17.2—MINAGRI 1989; Pieri 1989; Gietema 2005; Hartermink 2006).

Conclusions and Recommendations

Sweet potato is a low nutrient-requirement crop but its high yield potential is realised under adequate climatic, soil, and husbandry conditions. Rusenya, Rutambira, Caroline Lee, Anne-Marie, and Nyiramujuna cultivars confirmed their production potential as well as their adaptability to various ecological zones of Rwanda (Ndamage et al. 1992). Nutrient inputs, including organic supplies, must be applied according to soil fertility levels and other constraints. Generally, four situations for soil fertility have to be taken into account: (1) acid soils with high Al content, (2) acid soils low in organic matter, (3) soils with pH between 5.2 and 6.0, and (4) soils rich in nutrients. For better use of N, P, and K nutrients by sweet potato crop it is recommended to split applications especially for N, providing half at planting and another half three months later if the growth period exceeds five months. Under drought stress, mulching remains a prime choice. In future, a sweet potato improvement program should also pay attention to quality-related parameters such as dry matter and mineral content of root tubers and aerial biomass as well as to the nutrients taken up from soils by the crop.

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Chapter 18
Evaluation of Sweetpotato Varieties for the Potential of Dual-Purpose in Different Agroecological Zones of Kenya

B.A. Lukuyu, J. Kinyua, S. Agili, C.K. Gachuiri, and J. Low

Abstract Smallholder dairy farming is important in Kenya, however reducing farms into subdivisions over the past four decades has resulted in small farms. Meeting the nutritional requirements of high yielding dairy cows is now a constant challenge to the farmers especially during the dry season. Sweetpotato is a potential source of food and feed for smallholder farmers. The high biomass yield and quality of sweetpotato storage roots and vines are two of the most important factors that deserve attention when it is used as a feed. The present study evaluated six cultivars of sweetpotato for their potential as dual-purpose crops, biomass yield, and quality in different agroecological zones in Kenya. Six cultivars of sweetpotato were grown on farms in five sites located in the Central, South, and North Rift Valley regions of Kenya under rain-fed conditions. Two sites each were located in the high and medium altitude area while one was located in the low altitude area. All sites have a warm climate except the one at high altitude that experiences a cold climate. The cultivars were 103001, Gweri, Kemb-23, Kemb-36, Naspot-1, and Wagabolige. The vines of each variety were harvested at two different stages (75 and 150 days) post-planting. The 75-day treatment was ratooned again at 150 days post-planting. Agronomic observations were carried out during the long rainy season in 2010. Harvesting vines twice significantly ($P < 001$) increased forage yields but significantly reduced root yield in all the varieties. Gweri variety realized the highest forage yield but the lowest storage root yield indicating its potential as a forage variety. Kemb23, Kemb36, and Naspot1 produced appreciable amounts of vines and the highest root storage yield

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showing their potential as dual-purpose varieties. The effect of cultivar on forage yield varied with time of harvest. There was a high interaction between the cultivars and stage of harvest at 150 days after planting. Gweri, Kemb 23, and Kemb 36 showed some level of interaction with stage of harvesting at 150 days after planting. Across AEZs vine yields (t/DM/ha) ranged from 0.9 t/ha at high altitude (dry), 2.4 at high altitude (wet), 1.7 at low altitude (dry), and 2.8 medium altitude (wet). The root to vine ratios (R/V) obtained classifies cultivar 103001 as a low forage-high storage root cultivar while Gweri was classified as a forage cultivar in all AEZs. Four other varieties (Kemb-23, Naspot-1, Wagabolige, and Kemb 36) were identified as "best bet" dual-purpose varieties. Harvesting sweetpotato plants twice at 75 and 150 days post-planting increased vine yield by 34 % but also reduced tuber yields by 54 %. The practical implications of these results is that farmers in each AEZ will have at least one suitable forage, dual-purpose or root variety to choose from depending on the feed needs on farms.

Keywords Sweetpotato • Root yield • Vine yield

Introduction

Sweetpotato (*Ipomoea batatas*) is a tropical crop with a relatively short vegetative cycle. The tuber is usually for human consumption while the vines are used for animal feed (Woolf 1992). It is among the five most important food crops in developing countries (Horton 1988). In Kenya, most smallholders have adopted mixed crop and livestock systems that draw heavily on locally available feed ingredients (Lukuyu et al. 2011). The challenge is how to effectively improve productivity in complex systems where high population pressure has led to increasing competition between food grains and feed resources. Hence, smallholders in East Africa face severe livestock feed shortages especially in the dry season (Lukuyu et al. 2011). Some of the available feed resources include planted fodders such as Napier grass, crop residues, and natural pastures for grazing. There tends to be a shortage of high protein feed resources on farms in intensified farming systems. Quality feed concentrates are too expensive for many farmers. Availability and use of dual-purpose and forage sweetpotato varieties is a promising option of filling the current protein gap in feed resources on farms (Peters 2008). Selecting dual-purpose sweetpotato for feed purposes could have a significant impact on feed for smallholder pig, goat, and dairy production, as pigs in particular feed on both the roots and vines. This could be achieved through developing sweetpotato silage-based diets with locally available low quality feed resources (Kariuki et al. 1998). Kenyan researchers have found out that 4 kg of vines could replace 1 kg of dairy concentrate (Kariuki et al. 1998). However, in contrast to China, where 25 – 30 % of sweetpotato is used as animal feed, the potential of dual-purpose and forage varieties in sub-Saharan Africa (SSA) has not been fully exploited (Leon-Velarde et al. 1997). Presently, little land is allocated to sweetpotato production due to a lack of awareness of its potential and the lack of appropriate varieties for feed. The challenge is how to integrate enhanced sweetpotato production with improved livestock productivity to the benefit of smallholders and, ultimately, consumers. To accomplish this there is need for the right kind of dual-purpose varieties (bred for both animal feed and human consumption) or forage varieties (vines only). The present study was carried out to evaluate six cultivars of sweetpotato for their potential dual-purpose crops, biomass yield, and quality in different agroecological zones in Kenya.

Material and Methods

The experiment was carried out in three agroecological zones (AEZs) in the highlands of Kenya; namely low, medium and high altitude zones on selected farms during the long rainy season in 2010. The high altitude wet and dry zones were selected from Kieni East and Kieni West Districts, respectively, of Central Province of Kenya. The two wet medium altitude zones were located in Nandi District in the North Rift valley province of Kenya. The low altitude zone was located in Bomet District in the South Rift valley province. The low altitude zones comprise areas located <700 m above sea level, medium altitude areas are located 700–1,200 m above sea level, and high altitude zones are located in areas 1,200–2,300 m above sea level. Dry areas were considered to be zones with <750 mm of rainfall while wet areas receive rainfall of 750–1,500 mm of rainfall. Actual rainfall data was obtained in each site from the nearest weather station.

The on-farm participatory trials were researcher-led and farmer managed. Trial farms were selected through existing farmer groups in selected sites. Group meetings to sensitize and catalyze buy-in of the group members about the trial were held in each site. The groups selected trial farmers by consensus. The trials were replicated on three farms in each site. The trial farmers and the research team were invited to 1-day workshops to learn more about the trial, prepare work plans, and agree on the roles of all participants. The farmers provided land and labor and managed the plots while the research team provided all inputs and collected the data. Group members participated in all activities including planting and harvesting. Focus group discussions were organized with participating farmer groups to evaluate the varieties for yields, diseases, and taste (data not shown) and also determine the cost and benefits of growing sweetpotatoes.

The design of the experiment comprised six sweetpotato cultivars: Naspot1, 103001, Kemb 23, Kemb 36, Gweri, and Wagabolige × two cutting stages at 75 and 150 days post-planting. Kemb 36 was a local check. The control treatment was not ratooned at 75 days post-planting. The varieties were chosen from sweetpotato accessions pre-screened for various traits in the Kenyan national breeding program.

Plots measuring 12 m × 6 m with a 2-m border around it formed an experimental unit. Each plot was subdivided into six rows (1 m wide), and molded into ridges. Each row measuring 12 m was planted with 60 basal vine cuttings to give a total plant population of 360 vines per 9 m^2 plot. Each replicate was split into two portions generating a split-plot design. Each cultivar was randomly replicated three times in each block to make a randomized complete block design (RCBD). A population count of surviving vines in each unit were counted and recorded 30 days and 75 days post-planting. The surviving vines in half of split plot of the unit were defoliated (harvested) by cutting at 75 days post planting. At 150 days (end of the growing season) both the vines and tubers in the two portions were harvested by cutting the vines using a knife at a height of 20 cm above the ground to leave a uniform height of vine studs. The total fresh weight of the vines and tubers was taken and recorded. A fresh subsample of the vines and tubers weighing 0.5 kg was obtained from each replicate per cultivar, chopped into 3-cm lengths, then dried to constant weight for use in determining the vine and tuber total dry matter (DM) yield. Forage quality was examined at the physical level by leaf: stem ratio; chemically to determine crude protein concentration (CP%), neutral detergent fiber (NDF%) and acid detergent lignin (ADL%) contents and metabolizable energy (ME- Mj/kg) using the Near-infrared Spectroscopy Feed Analyzer technology (NIRS 2012).

Results and Discussion

The rainfall data obtained from all sites fell far below the normal average rainfall data recorded in all sites. All sites received <350 mm monthly rainfall throughout the year (Fig. 18.1). Plants in highest and coldest sites of Watuka in Kieni District of central Kenya located at 2,200 m above sea level in the high altitude wet zone did

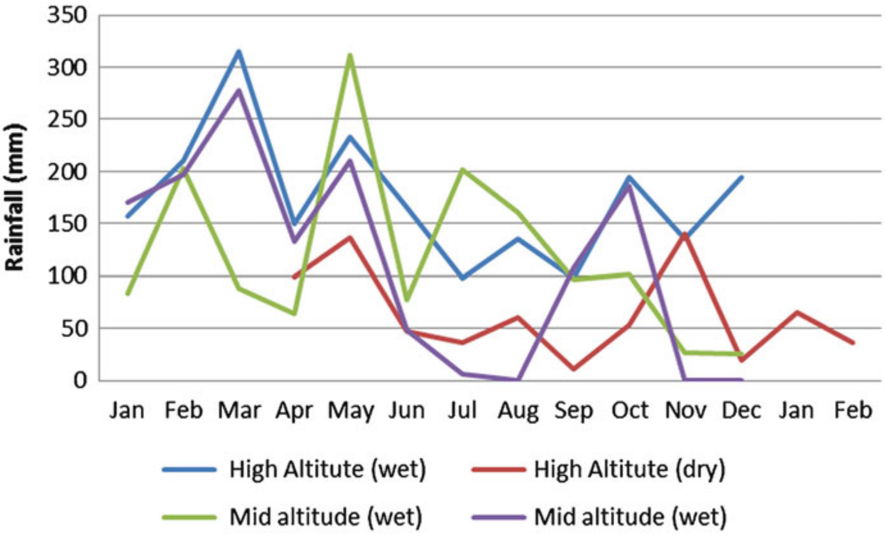

Fig. 18.1 The rainfall data record in trial sites in all agro ecological zones in 2010

Table 18.1 Means of dry matter production for sweetpotato vines and tubers (t/ha DM) showing main effect means and interaction for cultivar, cutting stage, and agroecological zones

Variable	Treatment	Sweetpotato vine yield (DM t/ha)			Sweetpotato tuber yield (DM t/ha)
Cultivar	103001	2.5 (±2.4)			2.1 (±1.5)
	Gweri	2.0 (±2.2)			1.1 (±0.9)
	Kemb 23	2.2 (±2.1)			1.9 (±1.6)
	Kemb 36	2.2 (±2.1)			1.7 (±1.3)
	Naspot 1	1.7 (±1.5)			2.7 (±2.0)
	Wagabolige	2.0 (±1.9)			1.9 (±1.6)
Cutting stage (days post planting)	75	1.1 (±1.4)			NA
	150 R	3.2 (±2.4)			1.2 (±0.8)
	150 UR	2.1 (±1.7)			2.6 (±1.8)
		Days post planting			
Cultivar × Cutting stage		75	150 R	150 UR	NA
	103001	0.6	3.0	4.1	NA
	Gweri	1.1	4.0	0.9	NA
	Kemb 23	1.6	3.4	1.6	NA
	Kemb 36	1.3	3.8	1.6	NA
	Naspot 1	0.5	2.3	2.2	NA
	Wagabolige	1.6	2.4	1.9	NA
AEZ	HA (dry)	0.9 (±1.1)			0.9 (±0.8)
	HA (wet)	2.4 (±3.2)			1.1 (±0.9)
	LA (dry)	1.7 (±1.1)			2.1(±1.2)
	MA (wet)	2.8 (±1.7)			2.7 (±1.8)
Seeds and significance					
Main effects	Cultivar	0.34^{ns}			0.28***
	Cutting stage	0.24***			0.16***
	AEZ	0.22***			0.22***
Interactions	Cultivar × cutting stage	0.59***			0.39^{ns}
	Cultivar × AEZ	0.71^{ns}			0.44^{ns}

Value in parentheses are standard deviation (SD)

R Ratooned, *UR* Unratooned, *HA* High altitude, *MA* Medium altitude, *LA* Low altitude, *AEZ* Agroecological zone, *NA* Not available

^{ns} $P < 0001$, $^{***}P < 0001$

not grow above stable height of 20 cm by the 75th day of harvest hence there was no data collected from the site. Sweetpotato plants were adversely affected by frost. This observation concurs with findings of May and Scheuerman (1998) who observed that sweetpotato is very sensitive to even a light frost and generally susceptible to very cold environments. This may also suggest that none of the tested varieties were tolerant to cold environments.

Overall, there was no significant difference between main effect cultivar means vine yields. However, there was a significant difference ($P \leq 0001$) between main effect means of tubers yields. Cultivars Naspot 1 gave the highest tuber yields of 2.7 t/ha DM and 103001 2.1. (Table 18.1). Overall, ratooning sweetpotato plants at 75 days post-planting significantly ($P \leq 0001$) increased vine yield by 34 % but also significantly ($P \leq 0001$) reduced tuber yields by 54 % (Table 18.1) over the

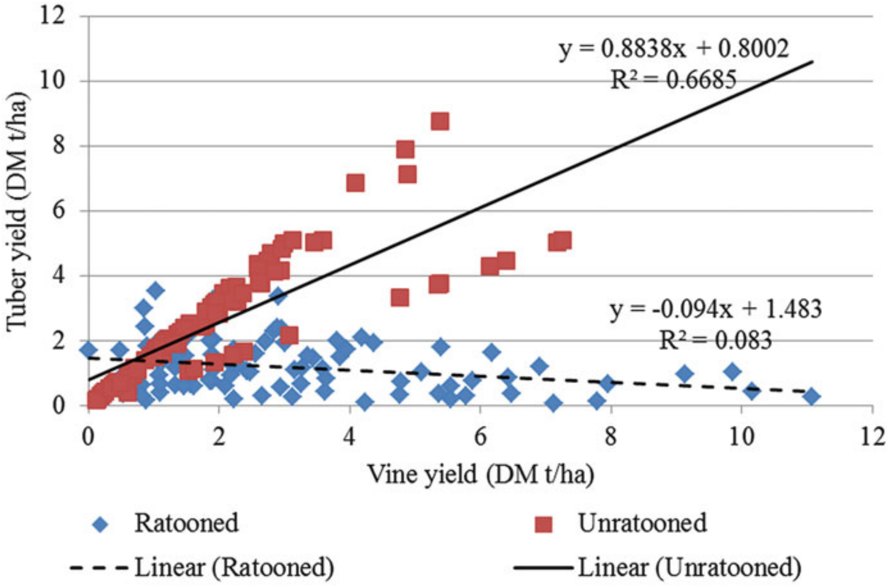

Fig. 18.2 Correlation between sweetpotato (SPV) root and vine yield (DM t/ha) of ratooned and unratooned plants

unratooned treatments. These results are similar to findings from previous studies that have showed that ratooning had a negative influence on storage root production in sweetpotato (Ruiz 1982; Paneque Ramirez 1992; Le Van An et al. 2003; Olorunnisomo 2007). This may be due to a negative correlation between leaf area/leaf growth and tuber yield shown by Mannan et al. (1992) and Le Van An et al. (2003). This finding may suggest the need for a longer cutting frequency to balance between forage and storage root production (Leon-Velarde 2001). There was a significant ($P \leq 0001$) interaction between cultivar and cutting stage. When ratooned and harvested at 150 days post-planting, Gweri, Kemb 36, and Kemb 23 produced the highest amount of vines, however they recorded the lowest tuber production (Table 18.1). Napot 1 gave the most balanced yield between vines and roots. Ratooning resulted in a positive correlation ($P < 0.05$) compared to unratooned plants (Fig. 18.2)

The ratios of vine to tubers of each cultivar were calculated based on ratio of storage roots over biomass [(R/(R + V)] to determine the root: vine (R/V) ratios shown in Table 18.2. Cultivars were rated according to the classification of Leon-Velarde (2001) as forage (F), $\mathrm{RV} < 0.2$; dual-purpose high forage, DP (F), RV $0.2 > \mathrm{RV} < 0.3$; dual-purpose high root, DP (R), RV $0.3 \geq \mathrm{RV} < 0.55$, and root (R), $\mathrm{RV} \geq 0.55$. Dual-purpose varieties which tend to produce more vines than storage roots were classified as dual-purpose high forage while those which produced more storage roots than vines were classified as dual-purpose high root. The Gweri

Table 18.2 The root: vine ratios (R/V ratio) showing clarification categories of the various sweetpotato cultivars in different agroecological zones

	HA (dry)		MA (wet)		LA (dry)		HA (wet)	
Cultivar	R/V ratio	Class	R/V ratio	Class	R/V ratio	Class	R/V ratio	Class
1031001	0.76	R	0.76	R	0.60	R	0.43	DP (R)
Gweri	0.16	F	0.20	F	0.20	F	0.07	F
Kemb 23	0.48	DP (R)	0.22	DP (F)	0.33	DP (R)	0.12	F
Kemb 36	0.58	DP (F)	0.28	DP (F)	0.28	DP (F)	0.07	F
Naspot 1	0.55	DP (R)	0.45	DP (R)	0.52	DP (R)	0.22	F
Wagabolige	0.42	DP (F)	0.30	DP (F)	0.36	DP (R)	0.14	F

R Root, *F* Forage, *DP (R)* Dual-purpose (more root), *DP (F)* Dual-purpose (more forage), *HA* High altitude, *MA* Medium altitude, *LA* Low altitude, *AEZ* Agroecological zone

variety was classified as a forage variety in all AEZs while 103001 was mainly classified as a root variety across all AEZs (Table 18.2). Varieties were classified differently across different agroecological zones, ensuring that farmers in each zone had at least one suitable dual-purpose variety except in the HA wet zone where most varieties exhibited forage characteristics. The high forage yield observed in the HA wet zone may be due to the tendency of receiving >1,500 mm of rainfall annually (Larbi et al. 2007; Wanda 1995) and reduced photosynthesis due to the cold (Dahniya 1979; Nwinyi 1992; Olorunnisomo 2007) leading to reduced formation of roots. The mean rainfall for the HA wet zone during a normal year is 1,072 mm during the growing season. Excessive moisture inhibits storage root development in early growth stages due to re-partitioning of dry matter accumulation to favor leaf production at the expense of the storage root development (Dahniya 1979; Mannan et al. 1992; Larbi et al. 2007). Four other varieties (Kemb-23, Naspot-1, Wagabolige, and Kemb 36) were identified as "best bet" dual-purpose varieties. Two varieties Naspot-1 and Wagabolige showed a positive correlation ($P < 0.05$) between tuber and vine yields (Fig. 18.3, Table 18.3).

A summary of the quality of vines for different varieties at different cutting stages is shown in Table 18.4. The crude protein (CP) vines ranged between 17 and 23 % while the neutral detergent fiber (NDF) ranged between 37 % and 42 %. As expected, vines harvested at 75 days post-planting had the highest mean CP of 22 % and lowest mean NDF of 40 %. Ratooned plants had a higher mean CP of 21 % compared to a mean CP of 18 % for unratooned plants 150 days post-planting. Sweetpotato vines contained an average of 8 Mj/kg metabolizable energy (Table 18.4). There are distinct percentage *in-vitro* digestibility's differences amongst cultivars (Fig. 18.4; Table 18.5). Naspot 1 and Wagabolige had the highest digestibility while the highest yielding forage variety Gweri had one of the lowest digestibilities. However, there is no significant relationship between root yield and vine digestibility (Fig. 18.4; Table 18.5) in all cultivars except Gweri suggesting that high root yield and high forage quality are not necessarily exclusive traits. However, overall there was a significant negative correlation between vine yield and digestibility for some of the varieties (Gweri, Naspot 1, and Kemb 36)

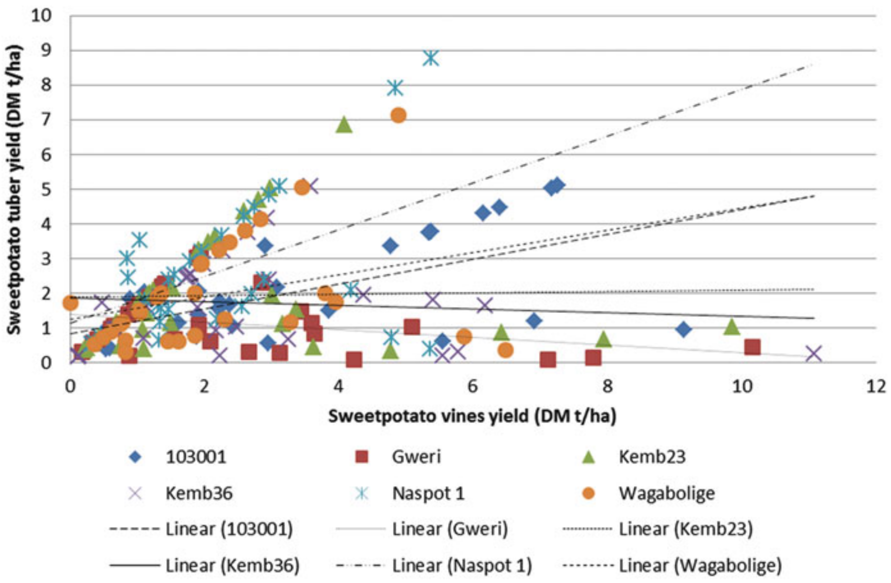

Fig 18.3 Correlation between sweetpotato (SPV) root and vine yield (DM t/ha) of cultivars

Table 18.3 A summary of y and R^2 equations obtained from correction between vine and tuber yields as shown in Fig. 18.3

Cultivar	Regression equation	R^2	Cultivar	Regression equation	R^2
1031001	$y = 0.3585x + 0.8213$	0.346	Kemb 36	$y = -0.0514x + 1.8505$	0.008
Gweri	$y = -0.109x + 1.3843$	0.093	Naspot 1	$y = 0.6749x + 1.1388$	0.233
Kemb 23	$y = 0.0198x + 1.8779$	0.000	Wagabolige	$y = 0.3206x + 1.2348$	0.108

(Fig. 18.4; Table 18.5) suggesting that tradeoffs may need to be considered when choosing between forage yield and the quality of some of the varieties while in other varieties it would be feasible to further improve quantity and quality traits in sweetpotato dual-purpose variety selection programs. The NIRS method used in this trial could be useful in such breeding and selection work (Table 18.6).

Practical Implications of the Results

The findings showed that the varieties were classified differently as dual-purpose, forage, or root varieties across different agroecological zones, ensuring that farmers in each zone had at least one suitable dual-purpose variety. This implies that farmers would have to make tradeoffs between forage, dual-purpose, and root varieties depending on feed needs on farms. It is likely that farmers facing acute

Table 18.4 A summary of the chemical composition of sweetpotato vines of different varieties at different cutting stages

Cultivar and cutting stage (days)	DM %	Ash%	CP %	NDF %	ADL (%)	ADF %	ME (Mj/kg)
103001	95	14	20	38	6	29	8
75d	95	15	23	37	6	27	8
Ratoon 150d	95	14	18	38	6	28	8
Unratooned 150d	95	14	18	42	7	31	8
S.E.D.	*0.5*	*2.6*	*4.2*	*3.8*	*2.9*	*0.7*	*0.7*
Gweri	95	15	20	40	7	31	8
75d	94	13	22	40	6	27	9
Ratoon 150d	96	16	21	39	7	31	8
Unratooned 150d	96	15	17	42	7	35	8
S.E.D.	*0.8*	*2.2*	*4.3*	*3.3*	*4.6*	*0.9*	*0.6*
Kemb 23	95	15	20	41	7	32	8
75d	95	14	21	42	7	32	8
Ratoon 150d	95	15	21	40	6	30	8
Unratooned 150d	96	15	18	41	7	33	8
S.E.D.	*0.4*	*2.1*	*3.4*	*3.9*	*2.4*	*0.7*	*0.5*
Kemb 36	95	16	21	38	7	30	8
75d	95	14	22	39	6	29	8
Ratoon 150d	95	18	22	37	7	30	7
Unratooned 150d	95	17	19	39	7	32	8
S.E.D.	*0.4*	*3.5*	*3.1*	*5.8*	*3.0*	*0.6*	*0.8*
Naspot 1	95	15	21	41	7	31	8
75d	94	14	24	39	6	28	8
Ratoon 150d	95	15	20	42	7	32	8
Unratooned 150d	95	14	18	42	7	33	8
S.E.D.	*0.6*	*1.4*	*3.2*	*3.8*	*3.5*	*0.6*	*0.5*
Wagabolige	95	16	20	41	7	32	8
75d	95	14	20	42	7	30	8
Ratoon 150d	96	20	21	39	7	35	7
Unratooned 150d	95	14	20	42	7	30	8
S.E.D.	*0.6*	*5.1*	*3.4*	*5.4*	*3.9*	*0.6*	*0.9*

DM Dry Matter, *Ash* (Not an abbreviation), *CP* Crude Protein, *NDF* Neutral Detergent Fiber, *ADL* Acid Detergent Lignin, *ADF* Acid Detergent Fibre, *ME* (*Mj/kg*) Metabolizable Energy (Mega joules/kg)

feed shortages would opt for forage or dual-purpose varieties. Currently, livestock is fed on the same sweetpotato varieties consumed by humans; some of these varieties are not necessarily the highest biomass yielders. Priority for selection for human consumption is based on taste and high Vitamin-A content. However, human consumption also cannot be ignored, particularly in rural poor communities. Thus this is not to suggest that farmers should replace all sweetpotato production with forage varieties, but rather to offer farmers both options depending on their food–feed needs.

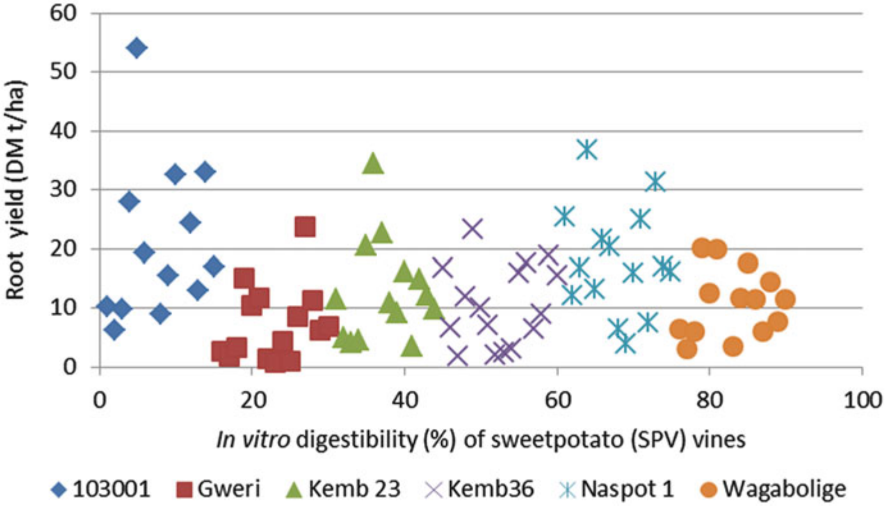

Fig 18.4 Correlation between sweetpotato (SPV) root yield (DM t/ha) and in-vitro digestibility (%) of different varieties

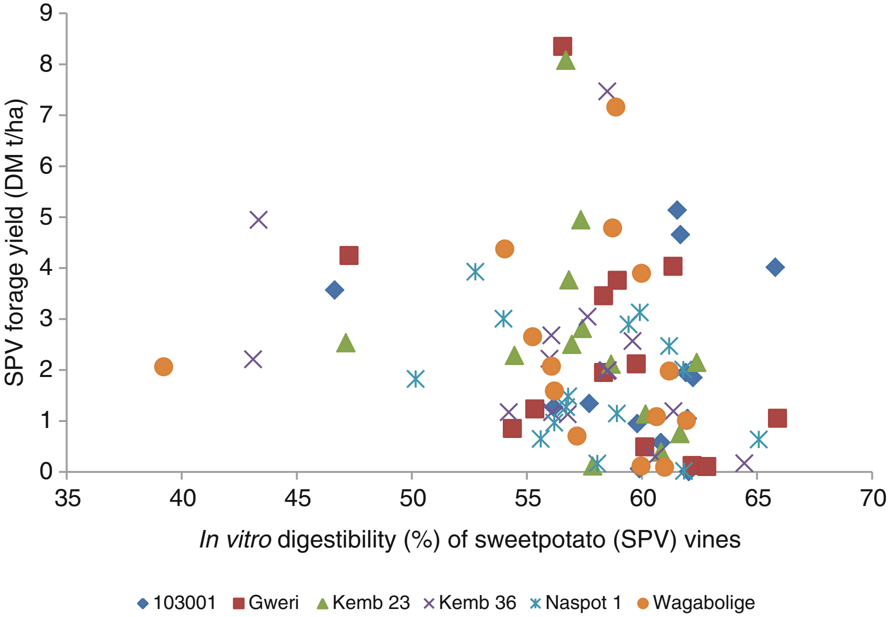

Fig 18.5 Correlation between sweetpotato (SPV) forage yield (DM t/ha) and in-vitro digestibility (%) of different varieties

Table 18.5 A summary of y and R^2 equations obtained from correction between in-vitro digestibility (%) of vine and tuber yields of different varieties as shown in Fig. 18.4

Cultivar	y – value	R^2 value	Cultivar	y – value	R^2 value
1013001 (NS)	$y = 0.4814x + 17.138$	$R^2 = 0.0291$	Kemb 36	$y = 0.2159x - 0.7963$	$R^2 = 0.023$
Gweri ($P < 0.05$)	$y = 0.3736x - 1.3188$	$R^2 = 0.068$	Naspot 1	$y = -0.2636x + 35.89$	$R^2 = 0.0168$
Kemb 23 (NS)	$y = 0.0796x + 9.8165$	$R^2 = 0.0015$	Wagabolige	$y = 0.1503x - 1.5961$	$R^2 = 0.0149$

Table 18.6 A summary of y and R^2 equations obtained from correction between in-vitro digestibility (%) of vine and tuber yields of different varieties as shown in Fig. 18.5

Cultivar	Y – value	R2 – value	Cultivar	Y – value	R2 – value
103001 (NS)	$y = -0.0108x + 2.6821$	$R^2 = 0.0008$	Kemb 36	$y = -0.1049x + 8.1907$	$R^2 = 0.1102$
Gweri ($P < 0.05$)	$y = -0.1904x + 13.6$	$R^2 = 0.1444$	Naspot 1	$y = -0.1483x + 10.073$	$R^2 = 0.2258$
Kemb 23 (NS)	$y = -0.148x + 11.101$	$R^2 = 0.0723$	Wagabolige	$y = -0.0271x + 3.952$	$R^2 = 0.0059$

Table 18.7 Costs and returns for producing and marketing of sweetpotato per hectare

	Unit	Units/ha	Value/unit (Ksh)	Value/unit (US$)	Total value (Ksh)	Value (US$)
Product outputs						
Sweetpotato vines	No. of vines	114,049	1.0	0.012	114,049	1,382
Sweetpotato roots	Ton	10.45	35,000	420	365,750	4,389
Total outputs (Ksh)					**479,799**	**5,771**
Variable costs		Units/ha	Cost/unit (Ksh)	Cost/unit (US$)	Total costs (Ksh)	Total costs (US$)
Land preparation	Man-days	15	1,141	14	17,110	207
Ridging	Man-days	8	713	9	5,703	69
Planting	Man-days	10	1,426	17	14,255	173
Weeding labour	Man-days	10	4,277	52	42,766	518
Harvesting	Man-days	10	3,992	48	39,917	484
Total variable costs					**119,752**	**1,452**
Gross Margin					**326,924**	**3,963**

Source: Data gathered from focused group discussion with one of the trial group farmers

In the present study forage sweetpotato varieties produced 5–8 t/DM/ha of vines in one season (4–6 months), the total annual vine production would reach 10–16 t/DM/ha when considered over the 2 cropping seasons. One ton of silage made from sweetpotato can produce energy 2,012 Mj, metabolizable energy (Mj ME/kg) enough to support a dairy cow weighing 250 kg and producing 6 L of milk per day for 67 days (assuming 6 kg intake per day) or 400 L of milk. Hence the annual vine production of 10–16 t/DM/ha can support 6–8 cows milking an average of 6 L of milk per day for 67 days or a total of 3,200–4,000 L of milk. In this case, forage sweetpotato can play a significant role in improving feed availability, quality, and reducing seasonal feed shortages for dairy cows, goats, and pigs. In order to understand the potential of adoption of these new sweetpotato varieties for food and feed, a gross margin analysis of the sweetpotato was conducted in one of trial sites (Table 18.7). The vines contribute to 24 % of the total revenues from growing sweetpotato and this could be higher if non-commercial tubers unsuitable for human consumption are considered as livestock feed. This clearly shows the importance of sweetpotato as a food and feed on smallholder farms.

Conclusion

The objective of this study was to evaluate different sweetpotato varieties for the potential of forage, dual-purpose, or root under different cropping regimes. The Gweri variety showed the highest potential as a forage variety while 103001 showed the highest potential as a root variety across all agroecological zones.

Four other varieties (Kemb-23, Naspot-1, Wagabolige, and Kemb 36) were identified as "best bet" dual-purpose varieties. Harvesting sweetpotato plants twice at 75 days and 150 days post-planting increased vine yield by 34 % but also reduced tuber yields by 54 %. The vine and tuber production of sweetpotato differed across the regions hence the varieties were classified differently across the different agroecological zones. The implication of this is that farmers in each zone, except in the high altitude wet zone, have at least one suitable type of variety where most varieties exhibited forage characteristics. Cultivars in high altitude cold areas were affected by frost and experienced slow growth and they tended to produce more vines than storage roots hence most of them were classified as forage. Farmers will therefore have to make tradeoffs between forage, dual-purpose, and root varieties depending on feed needs on farms. In addition, more effort is needed to evaluate for sweetpotato varieties that are suitable to high altitude areas and are tolerant frost.

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Part III
Drivers and Determinants for Adoption

Chapter 19
Livelihoods Heterogeneity and Water Management in Malawi: Policy Implications for Irrigation Development

**Tawina Jane Kopa-Kamanga, Darley Jose Kjosavik,
and Penjani Stanley Kamanga**

Abstract A study was conducted among 92 Nkhotakota Bua watershed irrigation households in Malawi to assess the extent of livelihoods heterogeneity and its impact on household water management choices. The study determined the economic importance of irrigation in relation to other livelihoods as a heterogeneity factor. Dichotomizing the livelihoods into water and non-water dependent provided a better framework for augmenting the heterogeneity of "irrigation livelihoods". Using a livelihood approach, the study further explored determinants of livelihood diversity and factors that affected performance of single livelihood components. The results indicated that some livelihoods are more irrigation-based than others and most irrigation households venture into other livelihood activities, notably, livestock production, rain-fed crop production, and selling dried fish. The study suggests that some livelihood components are water dependent while others are non-water dependent, e.g., livestock production is water dependent while selling groceries is not. Irrigation, like most water-dependent activities, is less profitable to non-water dependent households contributing only 24 % to their livelihood base than it is to water-dependent households with 62 % contribution. The study further notes that households allocate more resources to more profitable activities. Water-dependent households have more diversified income sources and relatively less

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nominal income than non-water dependent households who are better off by 29 %. Furthermore, irrigation reduces income inequalities among water-dependent livelihoods by 0.14 (Gini coefficient) but it has no significant effect among non-water dependent livelihoods. The results of this study argue against the common view that irrigation households have irrigation-based livelihoods. This view overshadows the water-dependency dichotomy of livelihood activities which has implications for water management. The study concludes that water management starts at the household level as households ration and that integrated water resources management can better be promoted from a livelihoods perspective.

Keywords Irrigation households • Integrated Water Resources Management • Livelihood diversity • Livelihoods heterogeneity • Water-dependency dichotomy • Water management

Introduction

Water resource depletion is of growing concern in irrigated agriculture as competition for water continues to increase among users and between uses (Mulwafu et al. 2003; Meinzen-Dick and Bakker 2001; Bruns and Meinzen-Dick 2000; GWP 2000). Generally, in sub-Saharan Africa (SSA), unreliable and inadequate water supply in combination with declining soil fertility, has led to low agricultural productivity (Merrey et al. 2005; Malawi Government 2002). This is one factor that has influenced the development and adoption of approaches such as integrated water resource management (IWRM) that are geared to ensure equitable, efficient, and sustainable allocation and utilization of water resources (Lankford 2003; Meinzen-Dick and Bakker 2001; Bruns and Meinzen-Dick 2000; GWP 2004). It has been observed in some quarters that IWRM is currently a dominant paradigm for water management (Merrey et al. 2005; Biswas 2004).

Water and irrigation policies in Malawi have greatly embraced the concept of IWRM (Mulwafu and Msosa 2005; Malawi Government 2002, 2004a) with particular emphasis on irrigation development and stakeholder participation (Malawi Government 1999). There has thus been an emergence of farmer-managed irrigation systems (FMIS) and increased private sector involvement in irrigation development (Kay 2001). In FMIS, the ownership and management responsibility of irrigation systems rests on farmers either partially or fully (Mckay and Keremane 2006). One of the challenges of this irrigation paradigm shift has been far-reaching consequences of overlooking the costs, risks, and complexities of irrigation, and failure to fit irrigation into the farmers' broader livelihood arena where decisions on resource allocation—including water—are made (Lankford 2003; Guijt and Thompson 1994). Failure to place irrigation within the broader framework of rural livelihood systems (de Haan and Zoomers 2005) has resulted in mismanagement of water and irrigation infrastructure, and consequently, under performance of most farmer-managed irrigation systems. Approaching IWRM from a livelihoods perspective as already advocated for in some literature (Merrey et al. 2005; Lankford 2003; GWP 2000, 2003) has potential to address this challenge.

This paper therefore locates irrigation within the livelihoods framework (de Haan and Zoomers 2005; Scoones 1998) in seeking to understand the interface of irrigation livelihoods and water management policy. It uses empirical data from field research that was conducted among 92 Bua Watershed Irrigation farmers in Malawi. Through assessment of livelihood activities and also the distribution of income among them, the economic importance of irrigation vis-à-vis other livelihood activities is determined. Furthermore, the paper dichotomizes livelihood activities into water-dependent and non-water dependent in order to unpack trade-offs in water allocation and use within, between, and among households. This dichotomy also helps to broaden the concept of multiplicity of water users and uses which is mostly narrowly viewed in a "one user – one use" context (Meinzen-Dick and Bakker 2001; Mulwafu 2000). The paper complements previous efforts to demonstrate how policy can target stages of irrigation livelihoods and development, and it adds that at any stage, "irrigation livelihoods" are bound to be heterogeneous. It is asserted that this approach would make policy "more focused and effective in financial, outcome and sustainability terms" (Lankford 2003: 818). The paper also draws insights from Guijt and Thompson's (1994) observation that regarding irrigation as an end in itself and not a means to an end implies alienating irrigation from other livelihood endeavors. The authors condemn such a reductionist view of irrigation. These two viewpoints form the foundations of this paper.

Overview of Irrigation Development in Bua Watershed

Irrigation development in Bua watershed started in the early 1970s with the establishment of Bua River Diversion Gravity-fed Irrigation System for rice production. The irrigation system was developed with funding and technical expertise from the Taiwanese Government. The scheme management was handed over to the Malawi Government and subsequently to farmers in 1994 (SFPDP undated). Between 1994 and 2004, the area under rice production in the scheme reduced drastically due to farmers' failure to maintain the irrigation structures as they lacked expertise and financial muscle. During this period, the scheme got external aid through Smallholder Flood Plains Development Project (SFPDP) to assist in rehabilitation which included construction of permanent irrigation structures (such as weir, sand trap, and pipeline) at the main works and reorganization of farmers into an association. It is worth noting that Bua watershed was managed under an open-access/common property regime. Individuals had bundles of rights defined by whether they were members of the Bua scheme or not. These rights included ownership, control, and use rights (Meinzen-Dick and Bakker 2001). In addition, the Bua scheme leased its area in 2003. While the scheme had ownership of the land, standing as an entity on its own, its members had only use rights. Bua irrigation scheme farmers paid a fee to use water in the scheme, and the scheme in turn paid for water abstraction rights in volumetric terms (SFPDP undated). On the other hand, Chisambo irrigation farmers and individual irrigators abstracted water for free from anywhere provided it was not within the Bua irrigation system. The argument on payment for water abstraction rights was that only schemes that abstracted above a certain amount of water per year should pay. Coincidentally, the actual amount (volume) was not mentioned in the documents such as the Malawi National Irrigation Policy. This overlooked aggregated volume of water abstracted collectively by small-scale irrigation schemes or individual irrigators. This fragmented approach to water allocation and hence water management, combined with other factors mentioned above, aggravated the water scarcity problem thereby increasingly threatening development of irrigation in the watershed.

Materials and Methods

Description of the Study Area

The study was conducted in the watershed of Bua River Basin in Traditional Authority (T/A) Mphonde in Nkhotakota, located about 220 km north of the capital Lilongwe in Malawi. The Bua Basin has an estimated area of 10,700 km^2 and a catchment area of 10,654 km^2 (Esser et al. 2005; Kidd 1983) stretching from Mchinji through Kasungu and Ntchisi districts to Lake Malawi in Nkhotakota District. It lies at latitude 12°S and longitude 34°E, and at an altitude of about 500 m above sea level (Malawi Government 2004b; Nkhotakota District Assembly 2005). Bua watershed in Nkhotakota has one big river, known as Bua, and a number of perennial and seasonal streams, such as Kasangadzi, Chisambo, Chankhombe, and Kalongo. Bua River has an average monthly flow of 68.25 m^3/s, a maximum flow of 136 m^3/s (in January) and a minimum flow of 0.5 m^3/s in October (SFPDP undated). The area receives an annual rainfall of about 685 mm with an average of 57 mm per month. Main crops grown are maize and cassava for food and rice, cotton, tobacco, barley, and sugarcane for cash income. Minor crops include groundnut, paprika, vegetables, beans, soybean, chilli, millet, cowpea, and sweet potato (Malawi Government 2004b; SFPDP undated). Crops are grown under both rain-fed and irrigated conditions.

Methodology

Fieldwork was conducted in 2006. The household survey questionnaire, focus group discussion, and key resource person interviews were the main sources of information. Key resource persons included officials from agriculture, environmental affairs, and irrigation departments at district level, as well as long-serving members of the schemes and scheme committee members. Data was collected from 92 households in 10 randomly selected villages out of 31 villages that participated in irrigation. Data included quantitative components of livelihoods portfolio such as assets, activities, and incomes from various sources including irrigated and rain-fed crop production, livestock production, remittances, and formal employment. The villages were selected based on proximity to Bua River with the furthest being at least 4 km away.

Data Analysis

Data from household questionnaires was statistically analyzed using Microsoft Excel, JMP, and Minitab statistical packages. Descriptive statistics including means, standard deviations, and percentages were run on variables such as crop, livestock, micro-enterprises, and other household incomes as well as on costs of production. A logistic regression analysis (Agresti 2002) was used to establish relationships between dependent and independent variables such as possible significant relationship between livelihood water-dependency (see section "The Dichotomy of Livelihood Activities") and independent variables such as respondents' level of education, household size, household irrigated area, and so on. Tests were run at a 95 % level of confidence. Household was defined as a unit of production and consumption (Overholt et al. 1985).

The Dichotomy of Livelihood Activities

Livelihood activities were defined in terms of whether they were derived from direct utilization of water or not, such that the study came up with two categories of livelihood activities namely, water-dependent and non-water dependent. Water-dependent livelihood activities were defined as those livelihood activities which households derive from direct utilization of water. Examples of such livelihood activities were irrigated crop production, fishing, beer brewing, vegetable growing (and selling), and livestock production. Non-water dependent livelihood activities were activities such as managing a grocery shop/hawking, weaving, remittances, rents, carting and ploughing, and formal employment (e.g., teaching). Following this dichotomy of livelihood activities, households deriving more than half of their gross output values from water-dependent activities were labeled water-dependent hence constituting water dependent livelihoods. Those deriving less than half of their gross output values from water-dependent activities were termed non-water dependent. This categorization was possible with a livelihood water-dependency ratio calculated as follows:

$$Livelihood\ \ water-dependency\ \ ratio = \frac{Water\ \ dependent\ \ household\ \ incomes}{Total\ \ household\ \ income}$$

Water-dependent household incomes were the sum of all household incomes from water dependent livelihood activities, and total household incomes were the sum of all household incomes (from both water and non-water dependent livelihood activities) within a household, that is the total gross output values. The ratio values ranged between 0 and 1. The greater the value (closer to 1), the more water dependent the household livelihood base would be, and the closer to 0 the value is, the less water-dependent the household livelihood base would be. Using this ratio presentation, 68 % of the households were categorized as water-dependent while the rest (32 %) were found to be non-water dependent.

Assessing Income Levels and Distribution

Gross output values (GOV) were used as a proxy for estimating livelihood status of households. Estimations were made on the value of entitlements that households could save, consume, invest, or exchange with other goods. A higher GOV signified a better or an improved livelihood (Lwesya 2004). GOV was calculated as the sum of values in terms of Malawi Kwacha (MK) (Exchange rate at time of survey: US $1 = MK 137) from different entitlements that households owned, and these included irrigated crop production given as the market value of total irrigation produce; rain-fed crop production given as the market value of total rain-fed produce; livestock production calculated from market value of the stock; off-farm and non-farm activities valued as gross wages; self-employment calculated as gross earnings; remittances and rental incomes valued as such; and other incomes valued accordingly (e.g., casual labor). However, households own labor was excluded to avoid duplication (Kamanga 2005; Campbell and Luckert 2002). Income distribution levels and contribution of various incomes to total household incomes were assessed using the diversity index for incomes (Kamanga 2005; Ellis 2000; Chang 1997) and the Gini coefficient (Kamanga 2005).

Results and Discussion

Defining Heterogeneity in Irrigation Livelihoods

Livelihood Diversification Among Irrigation Households

Livelihood portfolios of most rural households comprise a number of livelihood strategies with some being more predominant than others (Ellis 2000; Lankford 2003). Some households may have primarily irrigation-based livelihoods (Lankford 2003) whereby more than half of their livelihood base rests on irrigation, while other households may access more than half of their income from a range of livelihood activities. The former scenario can be termed as “specialization within diversification”. The specialization within diversification phenomenon dominated the previous livelihood policy thinking, which was tendered on the assumption

Table 19.1 Proportion of households by typology of specialization in irrigation (n = 92)

Specialization category	Proportion total sample (%)	Livelihood strategy
75–100 % of total household GOV[a] from irrigation	30	Highly specialized
51–74 % of total household GOV from irrigation	27	Relatively specialized
≤50 % of total household GOV from irrigation	43	Not specialized
Total	100	

Source: Field survey (2006)

Adapted from Ellis (2000)

[a] *GOV* Gross Output Value (see section "Assessing Income Levels and Distribution")

that rural people always chose a particular livelihood strategy among available livelihood options and choices (Ellis 2000; DFID 1998). Ellis (2000) noted that: "...official statistics and social scientific analyses prefer to identify people's place in the economy according to their main occupation and profession..." (p 3).

However, there has been a growing recognition of livelihood diversification as an option in itself (Ellis 2000) and not always a process of screening for a better option or a response to crisis (Davies 1996). Thus, households sometimes enter into diversification as a matter of choice (for example, as a coping strategy for the rural poor; or a means of accumulating wealth for the rural rich) and not always out of necessity (Ellis 2000; Ellis and Freeman 2004). Various approaches have been devised which aid in explaining activity profiles—and hence livelihood strategies—for rural households. One commonly used approach is the income portfolios approach, which captures activity profiles by analyzing income portfolios across households (Ellis and Mdoe 2003). This paper observed that the extent to which a community's livelihoods system is dependent on a certain livelihood activity is reflected in the level of income derived from that activity, and the impact of its absence in some livelihoods within the system. In support of this observation Ellis (2000) asserted that livelihood and income are related and individual or household income is the most direct and measurable outcome of the livelihood process. Like rural Tanzania and elsewhere (Lwesya 2004; Ellis and Mdoe 2003), households within Bua watershed irrigation community had livelihoods with varying degrees of diversification as well as specialization. They depended on a diverse portfolio of activities and income sources, including petty trading, livestock production, and rain fed and irrigated crop production. About 43 % of the households revealed a considerably high degree of diversification in their livelihood base while 30 % were highly specialized in irrigated agriculture (Table 19.1).

The table shows that there is heterogeneity in livelihood strategy as regards economic importance of irrigation activity among rural households. That is, the extent to which irrigation contributes to income portfolios of households varies greatly. The results therefore suggest that it is wrong to assume that irrigation households have irrigation-based livelihoods as most policy and literature reflect (Lankford 2003; Guijt and Thompson 1994). Variation in benefits accruing from irrigation defines to what extent a household's livelihood is irrigation-based.

Table 19.2 Household irrigation income contribution by level of livelihood dependency on water

Specialization category	% of water-dependent households (n = 63)	% of non-water dependent households (n = 29)
>50 % of total GOV[a] from irrigation	81	3
≤50 % of total GOV from irrigation	19	97
Total	100	100

Source: Field survey (2006)
Adapted from Ellis (2000)
[a] *GOV* Gross Output Values

This has implications for water management since irrigation consumes water and generates externalities. Households with irrigation-based livelihoods are more likely to adopt water management interventions than those with non-irrigation based livelihoods. This is based on economic theory of rationality (Vedeld 2005) which contends that individuals tend to allocate resources where they are likely to be gainers and not losers.

Within an irrigation system, farmers should be envisaged as being at different levels of irrigation livelihoods and therefore as having different interests and needs. For example, at Stage B (of irrigation development on a sigmoid curve) where irrigation livelihoods momentum grows (Lankford 2003), there will still be variability in attainment of output from irrigation among farmers. That is, "irrigation livelihoods" are likely to be heterogeneous regardless of stage of irrigation development. It is therefore vital that policy interventions take livelihood characteristics of irrigation farmers into consideration at any stage of irrigation development. This will have implications for farmer participation in the interventions and consequently on outcomes and sustainability of the interventions.

Total Household Incomes and Livelihood Water-Dependency

Apart from variability in irrigation income dependence, the households also varied in reliance on other water-dependent livelihood activities, which is another dimension of heterogeneity. About 68 % of the households were found to benefit more from water-dependent livelihood activities than others, so they had water-dependent livelihoods, while the rest of the households had non-water dependent livelihoods. Of the households with water-dependent livelihoods, only 19 % got less than half of their total income from irrigation, while for almost all non-water dependent households, irrigation income constituted less than half of their gross output values (Table 19.2).

There is a relationship between household dependence on irrigation and its livelihood water-dependency status as the extent to which a household depended on irrigation determined its level of dependency on other water-dependent livelihood options. While irrigation-based livelihoods can generally be considered water-dependent, not all irrigation households will have water-dependent livelihoods, as this will depend on the categories of other livelihood activities the households engage in. This revelation has implications for water management,

Table 19.3 Mean household income portfolios, by level of livelihood water dependency

	Water-dependent households (n = 63)	Non-water dependent households (n = 29)	All households (n = 92)
Source of income	Mean (MK)[a]		
Irrigation	87,696 (62)[b]	44,167 (24)	73,975 (49)
Rain-fed cultivation	22,984 (16)	85,324 (47)	42,634 (27)
Livestock	18,483 (13)	16,139 (8)	17,774 (11)
Self-employment	11,615 (8)	36,242 (20)	19,378 (12)
Other[c]	1,115 (1)	1,207 (1)	1,144 (1)
Total	141,893 (100)	183,079 (100)	154,875 (100)

Source: Field survey (2006)

[a] *MK* Malawi Kwacha (US$1 = MK 137)

[b] Numbers in parentheses are percentages of mean total household income

[c] Other includes income from non-farm, off-farm, and remittances

as it is likely to affect the adoption of water management options among irrigation households. It was found that mean household incomes from water-dependent livelihood activities were greater for water-dependent livelihoods than for non-water dependent livelihoods. On the other hand, mean household incomes from non-water dependent livelihood activities were greater for non-water dependent livelihoods than for water dependent livelihoods (Table 19.3).

It was also found that irrigation income contributed 62 % of the mean total household income for water-dependent livelihoods and 24 % of the mean total household income for non-water dependent livelihoods. This implies that irrigation was more important to the households with water-dependent livelihoods than it was to those with non-water dependent livelihoods. It is important to employ an inter/intra-household approach when assessing irrigation livelihoods for water management. Irrigation as a livelihood activity exists within the realm of the household livelihood system where decisions on resource allocation, including water are made.

There was a significant difference in mean total household income between water-dependent and non-water dependent livelihoods. Households with non-water dependent livelihoods were better off by 29 % than those with water-dependent livelihoods. The paper therefore contends that water-dependent livelihood activities were less profitable and therefore unattractive, and infers that given an opportunity, a household in Bua watershed community would rather engage in non-water dependent activities. For instance, one respondent, on being asked if he attended irrigation meetings, replied: "I do not attend irrigation meetings because I spend more time running my grocery shop." This meant the opportunity cost of attending an irrigation meeting to this man was higher than the expected gains from sitting in his grocery shop. It could imply that he benefited more from his trading than from irrigation.

The study finds that irrigation-based livelihoods are poorer than non-irrigation based livelihoods. This contradicts what has been documented elsewhere that farmers who venture into irrigation activity often have sufficient assets from other

Table 19.4 Mean household incomes with corresponding diversification indices, by livelihood water dependency

	Water-dependent households ($n = 63$)	Non-water dependent households ($n = 29$)
Source of income	Mean (MK)[a]	
Mean household income (MK)	141,893	183,079
Mean income diversification index	0.58	0.46

[a] *MK* Malawi Kwacha (US$1 = MK 137)

sources (Lankford 2003). Rather than questioning this stance by Lankford (2003), this article calls for a critical review of his assertion and argues that a case-by-case study would lead to a better understanding of irrigation livelihoods. Other livelihood activities alongside irrigation have to be taken into consideration as they all inform the livelihoods system (Ellis 2000).

Income Distribution Levels: Diversity and Inequality

There are varying schools of thoughts on the relationship between income diversity and rural livelihoods. One school of thought asserts that the more diversified household income sources are, the poorer the household would be. On the other hand, households with less diversified income sources would be better off (Vedeld et al. 2004). A second school of thought is that households may not be endowed with enough assets to diversify their income sources in which case they would be poorer. Richer households can have very diversified income sources where they have invested their productive assets efficiently. So it is the size of incomes from these sources that matters (Kamanga 2005) and not necessarily the number of income activities. The paper used an index of diversity to describe the livelihood activities and the distribution of total income between the activities that Bua watershed irrigation households engaged in (Table 19.4).

There was a significant difference in income diversity index between water-dependent and non-water dependent households. Water-dependent households were more diversified with less mean total household incomes than non-water dependent households. The smaller mean total household income for water-dependent households showed that in trying to allocate assets in pursuit of a more satisfying livelihood, households develop a wider income base. On the other hand, non-water dependent households had a larger mean total household income indicating that they were better off. Furthermore, the smaller diversity index (0.46) indicated some specialization in income sources for non-water dependent households.

It can be argued that water-dependent livelihood activities, irrigation inclusive, are not as significant in improving livelihood status (or in the livelihood portfolios) of Bua watershed irrigation communities. Thus, a shift away from irrigation would be an indication of an improvement in the welfare of a household.

Table 19.5 Gini coefficients with and without irrigation income, by household livelihood water dependency

Source of income	N	Gini coefficient with irrigation income	Gini coefficient without irrigation income	Change (Units)
Water-dependent livelihoods	63	0.34	0.62	0.28
Non-water dependent livelihoods	29	0.40	0.42	0.02
Total	92	0.38	0.52	0.14

Source: Field survey (2006)

Therefore it is important to consider how much of water management should be left under control of irrigation farmers (Sokile et al. 2003), taking into account the stage of irrigation development and also the heterogeneity of the households within the irrigation system. A Gini coefficient analysis indicated that irrigation income reduced income inequalities among Bua watershed irrigation households (Table 19.5).

The results show that there is a change of 0.14 units on income inequality among the households when irrigation income is deducted from the total household income. In other words, without irrigation, income inequality among the households is greater by 0.14 indicating that irrigation reduces income inequality. The effect of irrigation on income inequality is significantly different across the households. It is greater for households with water-dependent livelihoods unlike those with non-water dependent livelihoods. The Gini coefficient for water-dependent livelihoods with irrigation income (0.34) is significantly different from the Gini coefficient for the same group without irrigation income (0.62). This shows that irrigation plays a greater role in reducing income inequalities among the water-dependent households.

These findings support the idea of defining livelihood activities under the dichotomy of water-dependency and non-water dependency when studying irrigation, to better investigate inter- and intra-household livelihood characteristics as they affect water management. The paper argues that households with water-dependent livelihoods are likely to take up interventions aimed at better management of water, as they will be more adversely affected by any negative changes in the water resource than their counterparts. However, the challenge is to make irrigation activity a mainstay and not a transition or pastime activity as the results seem to suggest for Bua watershed irrigation farmers. Making irrigation a mainstay would be significant for maximizing returns from irrigation, and other water-dependent livelihood activities as well. Improvements (through system efficiency) in water use in irrigation systems are likely to release water for other livelihood activities thereby affecting the entire household livelihood base. Thus, disaggregated assessment of the economic importance of irrigation to households provides an opportunity for promotion of integrated water resource management approach from a livelihoods angle. The success of this depends to a large extent on stakeholder (farmer) participation (Merrey et al. 2005 and Sokile et al. 2003).

Bua Watershed Livelihood Adaptation

Choice of livelihood strategies is dependent upon a number of factors including capabilities one has such as social networks, skills, and physical assets (Ellis 2000). In his analysis of stages of irrigation development, Lankford (2003) identified factors that affect access to irrigation-based livelihoods, based on livelihood framework. He argued that natural and physical factors such as water, land, and labor; economic and financial factors such as market prices, inputs, and credits; human and social factors such as social cohesion and conflict resolution; other livelihood strategies; and skills and experience in irrigation and negotiation all play a role in determining and developing household's livelihood strategy. Similar observations were made from a regression analysis which examined factors that affect choice of livelihood strategies in the context of water dependent livelihood activities vis-à-vis non-water dependent livelihood activities among Bua watershed irrigation households. Self-employment opportunities (skills), availability of and access to water-dependent income sources, reliance on agricultural input credit, and size of irrigated area (natural asset) are among the factors found to be influential. The probability of a household having a less water-dependent livelihood increased with reduction in irrigated land and water-dependent income sources, an increase in self-employment opportunities, and less reliance on farm input credits.

Policy Implications for Water and Irrigation Development

The study findings have some important policy implications for irrigation development and water resource management. Variation in benefits accruing from irrigation, for instance, implies that households with primarily irrigation-based livelihoods are more likely to actively participate in water management interventions than those with non-irrigation based livelihoods. Therefore, policy should be cautious of this level of heterogeneity which seems to cut across all stages of irrigation development. That is, within any stage of irrigation development, policy should envisage the households as being at varying levels of "irrigation livelihood status" so that a livelihood assessment of an irrigation system can be considered to direct policy interventions.

While irrigation-based livelihoods are generally water-dependent, not all irrigation households will have water-dependent livelihoods, as this will depend on the type of other livelihood activities the households engage in. Thus, at household level, decisions are made to allocate water between different water-dependent livelihood activities, and priority is given to activities that the households find profitable. In that regard, irrigation may not always be a priority. Water management and irrigation policies should be formulated to provide incentives for investment in water management where irrigation is not a priority. This can be at any stage of irrigation development.

Defining livelihoods of irrigation households in terms of a water/non-water dependency dichotomy provides a better framework for analyzing livelihood characteristics from an integrated water resource management perspective. The study has shown that this unravels intra-household relations regarding engagement in irrigation vis-à-vis other livelihood activities. Where changes in irrigation water use do not only affect irrigation output but also output from other activities within a household, the household will be more willing to invest in irrigation and water management. On the other hand a household with less output from water-dependent livelihood activities may not be willing to invest in irrigation and water management. This would explain why there is always variation in response to interventions in water management between irrigation systems and among households within an irrigation system. It is thus worthwhile to look into intra-household competing water uses alongside inter-household competing water uses when addressing water management. The policy dimension of this finding cannot be overemphasized. The fact that non-water dependent households are better off would possibly imply that non-water dependent livelihood activities are more profitable. As such, households would rather allocate their assets or resources to non-water dependent livelihood activities where they will be utilized more efficiently than to water-dependent livelihood activities. The results suggest a strong relationship between irrigation, water management, and livelihoods, and therefore a case for a livelihood analysis dimension in integrated water management.

Conclusions

The paper has revealed that irrigation livelihoods are just as heterogeneous as irrigation schemes. While heterogeneity in irrigation schemes lies in the "non-uniformity of soils, weather, fields, cropping pattern and canal systems" (Smout and Gorantiwar 2005) among other things, irrigation livelihoods are heterogeneous in that they accrue benefits from irrigation variably. Another level of heterogeneity stems from varying dependence on water as a source of livelihood. While some households have water-dependent livelihoods, others have non-water dependent livelihoods. The paper has inferred that households with water-dependent livelihoods are likely to take up water management interventions as such interventions inform their livelihoods. The paper has argued against the wide view that irrigation households have predominantly irrigation-based livelihoods as is reflected in most literature and policy strategies. By dichotomizing livelihood activities of irrigation households, the paper has shown that some irrigation households have non-irrigation based livelihoods, and most of them are non-water dependent. In addition, water-dependent households, most of which have irrigation-based livelihoods, are poorer in terms of income than non-water dependent households. Furthermore, water-dependent households benefit more from irrigation than non-water dependent households. This is a very important policy dimension because it informs households' ability to participate in irrigation and water management activities.

The study results have also shown that as households make decisions around resource allocation rationally, more resources are allocated to more profitable activities. Where irrigation remains an unattractive and low-income livelihood activity as results for Bua watershed seem to suggest, investment efforts in water management are likely to be few and undesirable or even nonexistent. However, in cases where a household has a string of water-dependent livelihood activities, that may be an incentive for the household to invest in water. Finally, the paper concludes that the water-dependency/non-water dependency dichotomy of livelihood activities provides a better analytical framework for assessing intra- as well as inter-household trade-offs in water allocation, and helps in understanding the interface between irrigation, water management, and rural livelihoods.

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Chapter 20

Access to Subsidized Certified Improved Rice Seed and Poverty Reduction: Evidence from Rice Farming Households in Nigeria

B.A. Awotide, T.T. Awoyemi, and A. Diagne

Abstract This study assessed the impact of access to Subsidized Certified Improved Rice Seed (SCIRS) on poverty reduction among rice farming households in Nigeria, using cross-sectional data of 563 rice farmers selected from three states, representing the three major rice producing ecologies. Due to the problem of endogeneity and non-compliance, this study adopted Local Average Treatment Effect (LATE) estimation techniques to provide a reliable estimate of the impact of access to SCIRS on poverty reduction. The study showed an observed increase of 20 % in output for all the respondents. Farmers in the treated group had a 15 % increase in rice output and an 11 % increase in income after the intervention. Poverty incidence, and depth and severity by gender and rice ecologies reduced among the treated after the intervention. The result of the LATE estimate showed an impact of US$221.98 on revenue from rice production. However, the impact on revenue was higher among the male-headed households (US$441.41) than the female-headed households (US$142.16). The intervention was also pro-poor in nature, as it had a higher impact on the poor (US$430.07) than the non-poor (US$97.60) farming households. Therefore, granting farmers' access to SCIRS can be a route out of prevailing poverty in Nigeria. This study recommends that the existing seed certification and subsidy system should be properly monitored and implemented to ensure that farmers get access to seed of good quality at the right time and at affordable prices.

Keywords Access • Subsidized • Improved • Rice • Poverty • Nigeria

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Introduction

Nigeria is one of the poorest countries in the world, despite being a major oil exporter. The human development index (HDI), a composite measure of income and access to education and health services, of the United Nation Development Program (UNDP) placed Nigeria in position 142 among 174 countries in 1997 and in position 152 out of 175 in 2000 (UNDP, 2005). This low HDI reflects the situation with regard to poor access to basic social services in the country. The national poverty rates for 1980–2004 were: 28 % (1980), 46 % (1985), 43 % (1992), 66 % (1996), and 54 % (2004). Although the result showed appreciable decrease in poverty rates between 1985 and 1992 and between 1996 and 2004, the percentage of the population in poverty has maintained a steady increase from 17.7 million in 1980 to 68.7 million in 2004 (NBS, 2005). Poverty is not only widespread in Nigeria; it is also seen as a rural phenomenon. The percentage of poor people in rural Nigeria was 64 %, while the corresponding figure for urban centers was 43 % in 2005 (NBS, 2005). For most households living in the rural areas, agriculture is the main activity and previous analyses of poverty have shown that poverty is disproportionately concentrated among households whose primary means of livelihood is agriculture. Consequently, agriculture in Nigeria has the highest poverty incidence rate (63 %) among all occupational groups considered in the National Living Standard Survey (NLSS) conducted by the National Bureau of Statistics (NBS, 2005). A high proportion (48 %) of Nigeria's active population is involved in agriculture. This group of households also has the highest poverty depth (26.1) and severity (10.7) across all occupational groups compared with group averages of 17.5 for depth and 6.9 for severity.

In Nigeria several policies, programs, and strategies have been adopted to reduce poverty. Despite all of these, little has been achieved in terms of poverty reduction in Nigeria. Recently, in order to reduce poverty and mitigate the adverse effects of soaring food prices as a result of the global food crisis of 2008 on poor, rice farming households, an Emergency Rice Initiative (ERI) was formulated by AfricaRice in collaboration with other national and international organizations such as the International Fertilizer Development Company (IFDC) and Catholic Relief Services (CRS). The project was financed with the support of United States Agency for International Development (USAID) under its famine fund project (AfricaRice 2010). The broad objective of the project was to generate an increase in rice production, which was expected to lead to an increase in revenue and ultimately reduce poverty particularly within rice farming households. ERI adopted the seed voucher system to grant some randomly selected rice farmers' access to certified improved rice seed at a subsidized rate. (Certified rice seed is high quality seed devoid of impurities and has a high germination rate). However, the impact of this intervention on farmers' revenue and subsequent reduction in poverty has not been investigated. Thus, this study empirically investigated whether access to Subsidized certified improved rice seed (SCIRS) increases revenue of resource-poor farmers thereby decreasing their propensity to fall below the poverty line.

Materials and Methods

Poverty Measurement

The starting point for an appropriate poverty measurement is the calculation of the Poverty Line (PL). PL is the minimum acceptable standard of the welfare indicator (Ravallion 1992; Deaton 1997) and it separates the poor from the non-poor (Ravallion and Huppi 1991). Due to the absence of an official PL in Nigeria, several poverty related studies usually adopted the relative poverty lines, which are proportions of the average Per Capita Expenditure (PCE) (Canagarajah et al. 2001; FOS 1999; Okunmadewa et al. 2010). This study also utilized the relative poverty line approach, defined as the two-thirds of the mean value of the per capita consumption expenditure among the rice farming households in the study area. Thus, households with per capita consumption expenditure below the poverty line are classified as poor and non-poor otherwise. The standard Foster-Greer-Thorbecke (FGT) (1984) often refers to as the P_α class of poverty measures was adopted to generate the poverty profile of the respondents before and after the intervention for the treatment and the control group. FGT takes the form;

$$P_\alpha(y,z) = \frac{1}{n}\sum_{i=1}^{q}\left(\frac{Z-Y_i}{Z}\right)^\alpha \tag{20.1}$$

Where

Z = the poverty line
q = number of individual below the poverty line
n = number of individuals in the reference population
Y_{pi} = per capita consumption expenditure of the i$^{\text{th}}$ household
Z−Y_i = poverty gap of the ith household

$\frac{Z-Y_i}{Z}$ = poverty gap ratio
α = poverty aversion parameter and takes value 0, 1, 2.

When α = 0 in Eq. (20.1) the expression gives the headcount ratio, which is the share of poor people in the population. When α = 1 in Eq. (20.1), it gives the poverty depth, which is average amount of income necessary to raise the whole population above the poverty line. When α = 2, the squared poverty gap index (SPG) or the Poverty Severity Index (PSI) is generated. The PSI adds to the poverty gap ratio an element of unequal distribution of the poorest households' income below the PL. The FGT indices can be obtained for any subpopulation to get insights on how poverty varies across subpopulations, and so provide a poverty profile. That is:

$$\mathrm{P}_\alpha = \sum_{j=1}^{m} K_j P_{\alpha j} \tag{20.2}$$

Where: $j = 1, 2, 3..... m$, k_j is the population share of each group $p_{\alpha j}$ is the poverty measure of sub group j. The contribution of each group C_j to overall poverty can be calculated as follows:

$$C_j = \frac{K_j P_{\alpha j}}{P_\alpha} \tag{20.3}$$

Econometric Impact Evaluation

Impact assessment studies that failed to deal appropriately with biases arising from selection-on-observables and selection-on-unobservable usually present in observational data collected through household surveys have been seriously criticized in the literature, and their results were said to have no causal interpretation (Imbens and Wooldridge 2009; Heckman and Vytlacil 2005; Imbens 2004; Rosenbaum 2002; Heckman and Robb 1985; Rosenbaum and Rubin 1983; Rubin 1974). In order to overcome this problem, some past studies have adopted the Propensity Score Matching (PSM) method to deal with the self-selection bias problem and estimate the Average Treatment Effect (ATE) of agricultural technology on income (Mendola 2007; Mojo et al. 2007; Janvier and Awudu 2010). Other studies have also combined the PSM with the Double Difference (DD) method (Oni et al. 2007; Nkonya et al. 2007). However, a major drawback with the PSM method is that it cannot deal appropriately with the problem of selection-on-unobservable, although this may be controlled by the DD. It is worthy of note that even the combination of the two approaches still cannot tackle the problem of non-compliance. This study adopted a Randomized Control Trial (RCT) to eliminate the problem of selection on observables and in order to remove biases associated with selection on unobservables and non-compliance, a relatively new methodological approach "the non-parametric local average treatment effect (LATE)" framework was adopted to consistently estimate the causal effect of SCIRS on revenue (calculated as total income from rice production less total variable cost) from rice production.

Inverse Propensity Score Weighting (IPSW) Estimation of Average Treatment Effect

The methods that have been adopted in the literature to remove (or at least minimize) the effects of overt (selection-on-observables) and hidden (selection-on-unobservable) biases and deal with the problem of non-compliance or the endogenous treatment variable can be classified under two broad categories based on the types of assumptions they required to arrive at consistent estimators of causal effects (Imbens 2004). The methods designed to remove overt bias only are based on the "ignorability" or conditional independence assumption (Rubin 1974; Rosenbaum and Rubin 1983), which postulates the existence of a set of observed covariates $\boldsymbol{x}$, which, when controlled for, renders the treatment status t independent of the two potential outcomes y_T and y_C. According to Diagne et al.(2009) the estimators using the conditional independence assumption are either a pure parametric regression-based method, where the covariates possibly interacted with the treatment status variable to account for heterogeneous responses, or they are based on a two-stage estimation procedure where the conditional probability of treatment $P(t=1|\ x)\equiv P(x)$ (called the propensity score), is estimated in the first stage and ATE, ATE1, and ATE0 are estimated in the second stage by parametric regression-based methods or by non-parametric methods; the latter include various matching method estimators such as those used by Mendola (2007).

The conditional independence-based estimators of ATE, ATE1, and ATE0 that was adopted are the so-called inverse propensity score weighing estimators (IPSW), which are given by the following formulae (Imbens 2004; Diagne and Demont 2007; Diagne et al. 2009):

$$AT\hat{E} = \frac{1}{n}\sum_{i=1}^{n}\frac{(t_i-\hat{p}\,(x_i))y_i}{\hat{p}\,(x_i)(1-\hat{p}\,(x_i))} \tag{20.4}$$

$$AT\hat{E}\,1 = \frac{1}{n_1}\sum_{i=1}^{n}\frac{(t_i-\hat{p}\,(x_i))y_i}{(1-\hat{p}\,(x_i))} \tag{20.5}$$

$$AT\hat{E}\,0 = \frac{1}{1-n_1}\sum_{i=1}^{n}\frac{(t_i-\hat{p}\,(x_i))y_i}{\hat{p}\,(x_i)} \tag{20.6}$$

Where n is the total number of respondents (sample size), $n_1=\sum_{i=1}^{n}t_i$ is the number of treated farmers and $\hat{p}\,(x_i)$ is a consistent estimate of the propensity score evaluated at $\boldsymbol{x}$.

ATE = is the mean impact of the SCIRS in the population,
ATE1 = is the impact of the SCIRS on the subpopulation of the farmers in the treated group.
ATE0 = is the impact of the SCIRS on the subpopulation of the farmers in the control group.

A probit specification was employed to estimate the propensity score. However, the result of the ATE cannot be interpreted as the impact of the SCIRS on the farmers' revenue. Due to the fact that the ATE estimates do not correct for hidden bias (selection-on-unobservables) which is due to the fact that farmers' decision to receive the SCIRS could be based on some anticipated benefits which are unobserved by the researchers and unless these are controlled for, it could introduce biases into the analysis. Another vital problem is that of non-compliance which may arise as a result of the fact that the farmer may not stick to their assignment status. This implies that those in the treatment group may decide not to receive the SCIRS and those in the control may also manage to get the SCIRS at all cost and by all means. Hence it is necessary to use other methods that can eliminate these problems; this study therefore employed the Local Average Treatment Effect (LATE) estimation technique to provide a reliable estimate of the impact of access to the SCIRS on revenue from rice production.

Local Average Treatment Effect (LATE) Estimation Technique

The LATE estimation technique is basically an instrumental variable based method and was used by Heckman and Vytlacil (2005, 2007a, b), Heckman et al. (1997a, b), Card (2001), Imbens (2004), Abadie (2003), Imbens and Angrist (1994) to deal with overt and hidden biases and also deal with the problem of endogenous treatment or non-compliance. The method involves finding a variable (instrument) that is highly correlated with program participation, but is not correlated with unobservable characteristics affecting outcomes (Khandker et al. 2010). In other words, the IV-based methods assume the existence of at least one variable $\mathbf{z}$ called instrument that explains treatment status but is redundant in explaining the outcomes y_T and y_C, once the effects of the covariates $\boldsymbol{x}$ are controlled for (Rubin 1974; Rosenbaum and Rubin 1983). This approach depends on finding a variable omitted from the outcome equation but which is also a major determinant of the farmers' participation in the program. Observably, a major drawback of randomized or social experiment is that some of those randomly selected for the program may not want to participate. Thus, leading to the problem of non-compliance with the assignment status. Hence, being randomly assigned to receive the SCIRS only affects the outcome via actual receipt of the SCIRS.

In an attempt to solve the problem of non-compliance associated with RCT approach to impact evaluation, Imbens and Angrist (1994) divided the population into four groups based on compliance status: compliers (those who adhere to their assigned treatment), always takers (those who manage to always take the treatment regardless of their assignment), never takers (those who never take the treatment regardless of their assignment), and defiers (those who do the opposite of what their assignment asked them to do). The important point made by Imbens and Angrist (1994) is that only the mean treatment effect of the subpopulation of compliers can be given a causal interpretation and they called such a population parameter the Local Average Treatment Effect denoted by LATE.

Because the receipt of SCIRS is a farmer's choice even when they were given the seed voucher that would grant them access to the SCIRS, this led to the problem of non-compliance or the endogenous treatment problem discussed above. Therefore, the ATE estimate of the impact of the SCIRS on revenue from rice production has no causal interpretation. Thus, we needed the LATE estimate in order to have an estimate of the impact of SCIRS on revenue with a causal interpretation. In this study the treated farmers cannot receive the SCIRS without first receiving the seed voucher which granted them access to the SCIRS. Thus, the monotonicity assumption is trivially satisfied in the SCIRS case. This successfully rules out the cases of defiers and always takers. Therefore, for assessing the impact of the SCIRS on any farmer's revenue, the population was partitioned into only two distinct groups: the group of compliers, which is the group of potential receivers (those who will receive the SCIRS when they are giving the seed voucher), and the group of never takers, which is the group of farmers that will never receive it even when they are giving the seed voucher. Hence, the LATE estimate of the mean impact of the SCIRS on revenue from rice production has a causal interpretation, applies only to the subpopulation of potential receivers of the SCIRS.

Specifically, the Local Average Treatment Effect (LATE) estimates the treatment effect only for those who decide to participate because of a change in the instrument Z (Angrist 1998). This study adopted the simple non-parametric Wald estimator proposed by Imbens and Angrist (1994) and which requires only the observed outcome variable y, the treatment status variable t, and an instrument z. In order for IV estimate to be interpreted as the causal effect of a treatment on the compliers, both monotonicity and the independence assumption must hold (Imbens and Angrist 1994). The independence assumption requires that potential outcomes of any treatment state (y_T, y_C) are independent of the instrument z, i.e., $[y_{iT}, y_{iC}, T_i(1), T_i(0)]$ is independent of Z. The monotonicity assumption requires that the instrument makes every person more or less likely to actually participate in the treatment (no defiers). i.e.. $\mathrm{T_i}(20.1) \geq \mathrm{T_i}(0)$ for all i.

To give the expressions of the Imbens and Angrist (1994) LATE estimator and that of Abadie (2003), we noted that the receipt of the seed voucher is a “natural” instrument for the receipt of SCIRS (which is the treatment variable here). Indeed, firstly one cannot receive the SCIRS without being first randomly selected to receive the seed voucher. Second, it is natural to assume that the receipt of the seed voucher actually affected the household revenue only through the use of the SCIRS. That is being randomly selected to receive the seed voucher has no impact on revenue from rice production. The revenue of the farming households is actually affected only when the farmers use the SCIRS. Hence the two vital requirements of the seed voucher to be a valid instrument are met. Therefore, the mean impact of the SCIRS on the revenue of the subpopulation of compliers (i.e., the LATE) is as given by Imbens and Angrist (1994), Imbens and Rubin (1997), and Lee (2005):

$$\hat{\lambda}_{IV\quad LATE} = E(y_T - y_C | t_1 = 1) = \frac{E(y|z=1) - E(y|z=0)}{E(t|z=1) - E(t|z=0)} \tag{20.7}$$

The denominator in Eq. (20.7) is the difference in the probability of participation in the program (probability of T = 1) under the different values of the instrument. The right hand side of (20.7) can be estimated by its sample analog:

$$\left(\frac{\sum_{i=1}^{n} y_i z_i}{\sum_{i=1}^{n} z_i} - \frac{\sum_{i=1}^{n} y_i (1 - z_i)}{\sum_{i=1}^{n} (1 - z_i)} \right) \times \left(\frac{\sum_{i=1}^{n} t_i z_i}{\sum_{i=1}^{n} z_i} - \frac{\sum_{i=1}^{n} t_i (1 - z_i)}{\sum_{i=1}^{n} (1 - z_i)} \right)^{-1} \tag{20.8}$$

Equation (20.8) is the well-known Wald estimator. The Wald estimate gives the effect of the treatment on those whose treatment status was affected by the instrument, which is known as the Local Average Treatment Effect (LATE) (Imbens and Angrist 1994). These are those who in the absence of the seed voucher, would not have been treated but are induced to receive treatment by the assignment. They are often referred to as the compliers in impact assessment literature.

However, because the receipt of the SCIRS is not random in the population due to the fact that farmers in the control group may one way or the other obtain the SCIRS thus affecting their revenue. Also, farmers who were randomly selected to receive the SCIRS may eventually not receive it. In addition, the receipt of the SCIRS was also not randomly distributed in the population. It was targeted at rural-based rice farmers and also, only farmers in the three notable rice producing ecologies in Nigeria were targeted for intervention. Hence, the study adopted Abadie's estimation of LATE using the LARF, which requires the conditional independence assumption instead of the randomness assumption. Abadie's (2003) generalization of the LATE estimator of Imbens and Angrist (1994) to cases where the instrument z is not totally independent of the potential outcomes y_T and y_C, but will become so conditional on some vector of covariates x that determines the observed outcome y. With these assumptions, following Diagne et al. (2009) the following results can be shown to hold for the conditional mean outcome response function for the potential compliers:

f $(x,t) \equiv E(y \mid x, t; t_1 = 1)$ and any function g of (y, x, t) (Abadie 2003; Lee 2005):

$$f(x,1) - f(x,0) = (y_T - y_C|\boldsymbol{x}, t_1 = 1) \tag{20.9}$$

$$E(g(y,t,x)|t_1 = 1) = \frac{1}{P(t_1 = 1)} E(k \cdot g(y,t,x)) \tag{20.10}$$

Where

$$k = 1 - \frac{z}{p(z = 1|x)}(1 - t) \tag{20.11}$$

Equation (20.11) is a weighted function that takes the value 1 for a potential complier and a negative value otherwise. The function $f(x, \mathrm{t})$ is called a Local Average Response Function (LARF) by Abadie (2003). Estimation proceeds by a parameterization of the

$$\text{LARF } f(\theta; x, t) = E(y|x, t; t_1 = 1) \tag{20.12}$$

Then, using Eq. (20.5) with $g(y,t,x) = (y - f(\theta; x,t))^2$, the parameter θ is estimated by a weighted least squares scheme that minimizes the sample analog of $E\{\kappa\,(y - f(\theta; x,t))2\}$. The conditional probability $P(z = 1|x)$ appearing in the weight κ is estimated by a probit model in a first stage. Abadie (2003) proves that the resulting estimator of θ is consistent and asymptotically normal. Once, θ is estimated, Eq. (20.9) is used to recover the conditional mean treatment effect $E(y_T - y_C|x, t_1 = 1)$ as a function of x. The LATE is then obtained by averaging across x using Eq. (20.10)

For example, with a simple linear function $f(\theta, t, x) = \alpha_0 + \alpha t + \beta x$

Where: $\theta = (\alpha_0, \alpha, \beta)$, then $E(y_T - y_C|x, t_1 = 1) = \alpha$.

In this case, there is no need for averaging to obtain the LATE, which is here equaled to α. Hence, a simple linear functional form for the Local Average Response Function (LARF) with no interaction between t and x implies a constant treatment effect across the subpopulation of potential compliers. In line with other studies we postulated an exponential conditional mean response function with and without interaction to ensure both the positivity of the predicted farmers' revenue and heterogeneity of the treatment effect across the subpopulation of potential receivers. Because being randomly selected to receive the seed voucher is a necessary condition for the receipt of the SCIRS, it can be shown that the LATE for the subpopulation of potential receiver of SCIRS (i.e., those with $t\ 1 = 1$) is the same as the LATE for the subpopulation of actual receiver of the SCIRS (i.e., those with $t = zt1 = 1$).

Data and Descriptive Statistics

This study used both baseline data (2008) and post-voucher data (2010) collected by AfricaRice/NCRI through the multistage sampling technique. Osun, Niger, and Kano States were purposively selected to represent the three prominent rice producing systems—upland, lowland, and irrigated, respectively. From each of the three states, five rice producing Local Government Areas (LGAs) were selected and three villages were selected from each of the LGAs to generate a total of 45 villages. In all, 600 rice farmers were selected based on probability proportionate to the size of rice farmers in the villages, out of which 160 farmers received the SCIRS (treated farmers) and the others did not (control farmers). Data on socioeconomic/demographic characteristics, treatment status, expenditure, income, and institutional variables were collected using structured questionnaires. Data were analyzed using descriptive statistics, Foster-Greer-Thorbecke (FGT) poverty measure, IPSW, and LATE.

Ninety percent of the respondents had agriculture as their main occupation (Table 20.1). The majority of the sampled households (81 %) were headed by males, while only 19 % were headed by females. In terms of age distribution, a higher percentage (45 %) of the respondents were within the age group of 41–50 years, while a negligible proportion (<1 %) were above 70 years of age and a total of 76 % were between 18 and 50 years of age. This showed that most of the respondents were in their active and productive age and this could have a positive influence on rice yield. Household size was relatively higher in the study area. Most of the respondents (76 %) were within the household size group of 1–10 people per household. About 87 % of the respondents were natives of their respective villages and 52 % had spent between 41 and 60 years in the study area. The educational background of the household head revealed that most of the respondents (32 %) lacked formal education. While 15 % had at least primary education, 10 % had secondary education, and 40 % had Islamic education. Only 5 of the respondents representing 1 % had university education.

Table 20.1 Socioeconomic/demographic characteristics of the respondents

Socioeconomic/demographic characteristics	Frequency	Percentage
Age of household head		
18–30	30	5.3
31–40	147	26.1
41–50	252	44.8
51–60	116	20.6
61–70	13	2.3
>70	5	0.9
Gender of household head		
Male	454	80.6
Female	109	19.4
Educational background of household head		
No education	175	31.9
Primary education	81	14.5
Secondary education	53	9.5
High education	20	3.6
University education	5	0.9
Islamic	221	39.6
Household size		
1–10	429	76.2
11–20	125	22.2
21–30	9	1.6
Main occupation		
Farming	504	89.5
Non-farming	59	10.4
Native of the study area		
Native	491	87.2
Non-native	72	12.8
Years of residence in the village		
1–20	72	12.8
21–40	164	29.1
41–60	313	55.6
>60	14	2.4

Source: NCRI/AfricaRice field survey 2008 and 2010

Results and Discussion

Descriptive Statistics of Impact on Rice Output and Income

Table 20.2 presented the descriptive statistics of the impact of access to subsidized certified improved rice seed on rice output. The analysis showed that the average output of rice for the entire population of the respondents increased from 2758 kg in 2008 at the beginning of the project to 3309 kg at the end of the project in 2010, representing an increase of 20 % over and above the output before the intervention.

Table 20.2 Impact of access to subsidized certified improved rice seed on output and income

Year	Total (n = 563)	Treated (n = 160)	Control (n = 403)	Difference	Percentage difference
Impact of access to subsidized certified improved rice seed on output					
2008	2757.8	3191.2	2603.3	587.9	22.58
2009	2934.2	3152.2	2856.5	295.7	10.35
2010	3309.4	3659.4	3181.8	477.6	15.00
% Increase (2008–2010)	19.9	14.6	22.2	–	–
Impact of access to subsidized certified improved rice seed on income					
2008	160,846	194,613	148,804	45,809	30.78
2009	172,162	197,650	163,072	34,578	21.20
2010	190,662	215,194	181,913	33,281	18.29
% increase (2008–2010)	18.54	10.58	22.25	–	–

Source: NCRI/AfricaRice field survey 2008 and 2010

Furthermore, rice output for the farmers in the treated and control group increased by 15 % and 22 %, respectively, after the intervention.

In the same vein, change in income from rice production before and after the project and also between the treated and control was assessed and the result is presented in Table 20.2. The analysis showed that average income from rice production for all respondents increased by 19 % after the intervention in 2010. In addition, farmers in the treated group had an observed higher increase in income from rice production than the farmers in the control group after the intervention. Although, the before and after analysis of the income from rice production for the treated and control farmers appeared to reveal a higher increase for the control than the treated, this could be due to some underlying differences between the two groups prior to the intervention. Generally, however this observed improvement after the intervention cannot be attributed solely to access to subsidize certified improved rice seed, but due to the problem of self-selection and non-compliance (Heckman and Vytlacil 2005; Imbens and Angrist 1994). Thus, it is not appropriate to interpret these observed differences as the impact of the intervention, which implies that the observed differences have no causal interpretations.

Poverty Profile by Treatment Status

The poverty profile of the respondents was assessed by treatment status, with a view to examining how much difference and improvement in poverty indices has been generated by the access to subsidized certified improved rice. As presented in Table 20.3, the treated farmers had a lower poverty incidence, depth, and severity compared with the farmers in the control group. The poverty profile by gender showed that poverty incidence, depth, and severity among the female in the treated was lower than those in the control group. Also, poverty reduced across all the rice producing ecologies. However, the upland rice ecology had a higher significant

Table 20.3 Poverty profile by treatment status

Poverty profile by gender		Treated	Control	Percentage change
Male	P0	0.3645	0.4098	11.05
	P1	0.1219	0.1833	33.49
	P2	0.0554	0.0973	43.06
Female	P0	0.5738	0.5769	0.53
	P1	0.2356	0.2971	20.70
	P2	0.1255	0.1816	30.89
Poverty profile by rice ecologies				
Lowland	P0	0.3914	0.4706	16.83
	P1	0.1421	0.1975	28.05
	P2	0.0696	0.1009	31.02
Upland	P0	0.3125	0.4865	35.77
	P1	0.1302	15.42	15.56
	P2	0.0426	0.0874	51.26
Irrigated	P0	0.4600	0.5306	13.31
	P1	0.1755	0.2588	32.18
	P2	0.0894	0.1480	39.59

Source: NCRI/AfricaRice field survey 2008 and 2010

Note: P0, P1, P2 represent poverty headcount, depth, and severity, respectively

reduction in all poverty indices. This implies that access to the subsidized certified improved rice seed had reduced overall poverty among the treated farmers. However, this also cannot be given any causal interpretation due to the problem of endogeneity and non-compliance.

Econometric Analysis of the Impact on Revenue from Rice Production

Revenue from rice production was calculated as the difference between total income from rice production and the total variable cost of production. The revenue is also referred to as the gross margin and is a measure of profitability of an enterprise. The empirical result of the impact of access to SCIRS on revenue from rice production is presented in Table 20.4. The result showed that access to SCIRS had a positive and significant impact on revenue from rice production in Nigeria. Specifically, the LATE estimate revealed that access to SCIRS increased revenue by ₦34,851.06 (US$222). The result further revealed that the impact was much higher among the male (₦69,302.03 (US$441)) headed households than the female (₦22,319.60 (US$142.16)) counterparts. The intervention was also pro-poor in nature, as it had a higher impact on the poor (₦67,520.63 (US$430.06)) than the non-poor (₦15,323.93 (US$97.60)) farming households. In terms of causal effects, the estimate of LATE seems to be similar to those of the ATE – IPSW techniques.

Table 20.4 Econometric analysis of the impact on revenue from rice production

Estimates	Parameter	Robust std. error	Z-value
Inverse propensity weighting (IPSW)			
ATE	7827.24**	3835.88	2.04
ATE1	11,392.86***	3396.42	3.35
ATE0	6644.33	4511.43	1.47
LATE by WALD estimators	13,575.00*	7490.89	1.81
LATE by LARF	34,851.06***	10,954.29	3.18
LATE by LARF estimate by gender and poverty status			
Impact by Gender	69,302.03***	399.68	6.39
Male	69,302.03***	399.68	6.39
Female	22,319.60**	9932.40	22.25
Impact by poverty status			
Poor	67,520.63***	54,760.32	5.27
Non-poor	15,323.93	30.21	1.23

Source: NCRI/AfricaRice field survey 2008 and 2010
Legend: *** significant at 1 %, ** significant at 5 %, * significant at 10 %

However, the LATE estimates are quite different from the ATE estimates. More importantly, the ATE estimates of the impact of access to SCIRS on poverty reduction have no causal interpretation due to the problem of non-compliance.

Determinants of Revenue from Rice Production

The determinants of revenue from rice production as given by their LARF are presented in Table 20.5. The result revealed that apart from access to subsidized certified improved rice seed, there were other socioeconomic characteristics of the farming households that significantly influenced revenue. These variables included gender, household size, secondary occupation, Agricultural Development Program (ADP), and the National Cereal Research Institute (NCRI). In the same vein a number of coefficients for the interacted terms were also statistically significant, thus confirming the heterogeneity of the impact of SCIRS on household revenue from rice production. The F statistics of 23,709.15 for the joint significance of the interacted terms as well as the non-interacted terms indicated that they were jointly, statistically significantly different from zero. For the non-interacted term, the coefficient for gender (0.36) of household head was positively significant, meaning that male-headed households had higher revenue than female-headed households. The coefficients for secondary occupation (9.65), ADP (0.39), and NCRI (1.45) were positively significant, suggesting that farmers that had a secondary occupation, contact with ADP extension agents, and a relationship with NCRI had higher revenue. The coefficient of household size (0.062) was however positively significant, suggesting that larger households had higher revenue. This could be

Table 20.5 Estimated coefficient of the LARF for revenue from rice production

Per capita household expenditure	Coefficient	Standard error	T-statistics
Coefficients of the non-interacted terms			
Access to SCIRS	9.445	1.132	8.34***
Gender of household head	0.355	0.208	1.70*
Years of formal education	0.015	0.014	1.08
Age of household head	0.016	0.011	1.45
Household size	0.062	0.021	3.02***
Secondary occupation	9.645	0.535	18.04***
ADPdum (Contact with ADP extension agents)	0.392	0.201	1.95*
NCRIdum (Relationship with NCRI)	1.445	0.204	7.09***
Coefficients of the interacted terms			
Gender_SCIRS	0.664	0.808	0.82
Education_SCIRS	0.005	0.016	0.31
Age_SCIRS	−0.005	0.014	−0.32
Household size_SCIRS	−0.044	0.030	−1.45
Secondary activities_SCIRS	−9.364	0.674	−13.89***
ADPdum_ SCIRS	0.138	0.786	0.18
NCRIdum_ SCIRS	−1.195	0.879	−1.36
R-squared	0.45		
Adjusted R-squared	0.43		
Wald test for the joint significant of all coefficient	23709.15***		
Wald test for the non-interacted terms	112.20***		

Source: NCRI/AfricaRice field survey 2008 and 2010
NCRI National Cereal Research Institute
Legend: *** significant at 1 %,* significant at 5 %

explained by the fact that larger household size provides a source of family labor and hence reduced expenditure on farming and increases household revenue from rice production. Furthermore, the negative significance of the interacted term for secondary occupation suggests that the impact of access to subsidized certified improved rice seed on revenue would be smaller among those farmers that had no secondary occupation.

Conclusion and Policy Recommendations

This study assessed the impact of access to subsidized certified improved rice seed on poverty reduction among rice farming households in Nigeria. The study discovered that granting farmers access to certified improved rice seed at a subsidized rate had a positive and significant impact on revenue and could reduce the probability of a farmer falling below the poverty line. The existing seed certification should be intensified and the present seed subsidy program should be adequately monitored and well implemented to ensure farmers get seed at affordable price.

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Chapter 21

Factors Influencing the Adoption of Improved Rice Varieties in Rwanda: An Application of the Conditional Logit Model (CLM)

J.S. Mutware and K. Burger

Abstract This study investigates the factors influencing the adoption of improved rice varieties by small- scale rice farmers in Rwanda. The Conditional Logit Model (CLM) was applied to explore the variety attributes and farm household characteristics influencing the farmers' choice among different alternatives. The model is based on random utility maximization and makes the probabilities of the choice of variety dependent on variety-specific attributes and farm household-specific characteristics. A sample size of 180 rice farmers interviewed was randomly selected from six rice growing marshlands. Results revealed that a majority of rice farmers (78 %) had adopted improved varieties but the proportion of land cultivated to these varieties was still low (ranging from 0.05 to 0.2 ha). The maximum likelihood analysis showed that the prices of seeds and of paddy and the yield are variety-specific attributes that significantly influence the farmers' choice of an improved rice variety. The higher the price of seed, the lower the likelihood of adoption; the higher the price of paddy and yield, the higher the likelihood of adoption. Also, farm size, labor availability within a farm household, and access to financial facilities significantly influence farmers' decisions to adopt improved rice varieties. The findings suggest that future policies should make efforts to improve the seed supply system among farmers to increase the intensity of use of improved varieties. In addition, the prices of paddy should provide a market incentive that increases the likelihood of adoption through market development.

Keywords Factors influencing adoption • Rice • Conditional Logit Model • Likelihood of adoption • Variety-specific attributes

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Introduction

Rice is a staple food for 50 % of the world's population and about 33–49 % of the world's population entirely depends on it (Edet and Borating 2008). The crop accounts for over 21 % of global caloric intake (Wailes et al. 1998). In sub-Saharan Africa (SSA), rice is among the major staple foods for the rapidly increasing population; its consumption annually increased by 4.4 % in the period 1961–2003 (CIGIAR 2006). Rice is ranked the fourth most important cereal in terms of production after sorghum, maize, and millet, occupying 10 % of the total land under cereals and contributing 15 % of total cereal production (CIGIAR 2006).

Since the 1960s, research aimed at adapting improved crop varieties to subtropical and tropical conditions has generated high pay-offs and pro-poor impacts. Indeed, it is believed that the rapid advances in biological and informational sciences promise greater impacts still untapped for the benefit of the poor (WDR 2008). The adoption of improved rice varieties has registered significant progress, especially in Asian countries, through the Green Revolution innovations (Feder et al. 1985). Empirical evidence showed that high yielding varieties were adopted at exceptionally rapid rates in areas where the new varieties were technically and economically superior to local varieties (Feder et al. 1985).

In developing countries, farmers have planted the largest proportions of land to non-improved varieties in predominantly traditional farming systems. Several factors explain the low level of adoption and/or the low intensity of use of improved agricultural technologies. These include individual households' specific characteristics, the broader mix of crops grown in the region, agro-ecological complexities and the heterogeneity of the region, the lack of infrastructure, markets and supporting institutions, and the gender differences in labor responsibility and access to assets (WDR 2008). Consequently, crop productivity is very low in these countries.

In Rwanda, low crop productivity is mainly due to the use of low yielding planting materials and traditional techniques in farming systems (MINECOFIN 2005). For around two decades, the Government of Rwanda has been undergoing major agricultural policy reforms to improve productivity. Under the ongoing Crop Intensification Program (CIP), rice has been identified among the priority and strategic crops for rural poverty reduction and food security in Rwanda. A number of opportunities make rice one of the strategic agricultural commodities that the country needs to feed its increasing population while making optimal use of the limited land resource. The crop is better adapted to flood-prone valleys than other cereal and vegetable crops; it is easy to handle and store thereby reducing postharvest losses. It has a wide utilization base as animal feeds, is a substrate for mushroom growing, and has potential to be an export in the region (MINAGRI 2005).

Introduced in the 1960s, rice has increasingly become a major cash and food crop for the majority of small-scale farmers and consumers, especially in the urban areas of Rwanda. Varieties (from China) introduced to farmers were *Zhongeng*, *Yurnertian 01*, *Yun keng 136*, *Xinan 175*, and *Yun yine 4* (all locally called *kigori*). These have been the most commonly grown varieties for the past 30 years or more (with an average yield between 1 and 2.5 t/ha). Towards the 1980s, other varieties, such as *Basmati*, *IRON*, *IR 6*, etc (maximum yield of 3 t/ha) were also introduced (Jagwe et al. 2003).

In 2004 and 2005, the rice research program of the former Institut des Sciences Agronomiques du Rwanda (ISAR) introduced high yielding varieties (7–10 t/ha) such as *Tox 4331- Wat 91-3-1-1-1*(local name *gakire*); *Wat 1395-B-24-2* (local name *intsindagirabigega*), *Tox 4331-Wat 86-3-4-2-1* (local name *intsinzi*), *Nerica*; *WAT 54*-TGR-1-5 (local name *muturage*) and *Facagro 56* (ISAR 2004). Since then, little has been known about their adoption. By investigating their adoption status, this study informs rice research and extension processes to focus on variety attributes with high probabilities that many farmers will adopt the varieties.

Model Conceptual Framework

We assumed that a farmer has j improved rice varieties from which to choose. Each variety, *j*, can be described by a vector of specific attributes, Y*j*, which include seed price, paddy price, and yield. Based on these attributes, a farmer can infer how much utility (profit) each variety will produce for the consumption goods that the variety offers.

We further assumed that another vector, X_i, containing farm household characteristics including farm size, household size, and an institutional factor (access to financial services). These factors could affect the demand by a farm household for improved rice varieties.

Let the utility level of *jth* variety for *ith* farmer be given by U (Y_j, X_i). This utility depends on an interaction of the variety attributes with those of farmers. Utility may have random elements so that all farmers with X_i are not assumed to have the same tastes:

$$\mathrm{U}\left(\mathrm{Y}_j, \mathrm{X}_i\right) = -\left(\mathrm{Y}_j, \mathrm{X}_{ij}\right) + \varepsilon_{ij} \tag{21.1}$$

Assuming that the non-random part of the utility is a linear function of both variety and farm household characteristics, we get:

$$\mathrm{U}\left(\mathrm{Y}_j, \mathrm{X}_i\right) = \mathrm{Z}_{ij_1}\beta 1 + \mathrm{Z}_{ij_2}\beta 2 + \mathrm{Z}_{ij_3}\beta 3 + \ldots + \mathrm{Z}_{ij_\mathrm{k}}\beta \mathrm{k} + \varepsilon_{ij} \tag{21.2}$$

Where β is a vector of parameters, Z_{ij} are the variables that affect utility, and k is the total number of variables. Z may include variables that describe the elements of Y (i.e., the variety attributes) or interact Y and X (farm household characteristics). The farmer must determine the best choice that maximizes his expected utility.

For example, variety *j* will be chosen if its utility level is higher than any other utility level among all j choices as:

$$\mathrm{U}\left(\mathrm{Y}_j, \mathrm{X}_i\right) > \mathrm{U}(\mathrm{Y}_k, \mathrm{X}_i) \quad \text{for all} \quad j \neq k \tag{21.3}$$

The analysis of this theoretical framework is treated using the Conditional Logit Model (CLM). A description of this model and the justification for estimating the variety choices this way are described in the next section.

Choice Between Improved Rice Varieties: The Conditional Logit Model (CLM)

The theoretical framework of the CLM emphasizes a number of points that must be addressed in estimating how farm households choose among improved rice varieties. First, there is considerable heterogeneity among improved varieties that must be sufficiently characterized. Improved varieties vary widely in different points including seed price, paddy price, and yield. Secondly, match-specific information is a key part of the model since the compatibility of improved varieties within the prevailing farming system may be different across farm households. After all, the framework requires that a model adequately captures the full range of the opportunity set of potential farm households.

To understand how farm households make their decisions among different improved varieties, an empirical model should explore the trade-offs between the variety selected and the alternatives not chosen.

The model adopted for this study follows McFadden's CLM framework based on a random utility maximization. The model makes the choice probabilities dependent on alternative attributes as well as on farmer-specific characteristics (Maddala 1983). The rationale behind this model is that when consumers make a choice, they maximize their perceived utility subject to constraints on expenditure (Maddala 1983). The model assumes that an individual, when faced with the choice of one out of several mutually exclusive alternatives, assigns a utility to each choice and then chooses the one with the highest utility (Markley 2007).

The CLM is very suitable for the improved rice variety choice framework since it makes use of wide and detailed information on alternatives, can explain match-specific details, and allows for multiple alternatives. The CLM has been widely used in various domains; these include, for example, transportation (McFadden 1974), residential location decisions (McFadden 1978), firm location (Guimarães et al. 2003), college choice decisions (Long 2004), food product preferences (Markley 2007), interstate migration (Davies et al. 2001; Christiadi and Cushing 2007), and agricultural technology adoption (Barham et al. 2004).

To estimate the CLM, the data are organized as pair-wise combinations of each farm household *i* with each variety *j*. By using these combinations, the CLM is made up of *j* equations for each farm household *i*, with each equation describing one of the alternatives. This allows for match-specific variables based on the interaction of individual *i* with improved variety *j*. The CLM then calculates the probability of choosing one variety among others with the dependent variable equal to one for the alternative that was chosen. Following McFadden (1974), we assume that the ε_{ij}'s are independent and identically distributed with the extreme value distribution; the conditional logit functional form becomes:

$$P_r(E_{ij}) = e^{Z_{ij}\beta} / \left(e^{Z_{i1}\beta} + e^{Z_{i2}\beta} + \ldots + e^{Z_{ij}\beta}\right) \tag{21.4}$$

Where $Z_{ij}\beta = \beta_1(X_{i1}Y_j1) + \beta_2 Y_{j2} + \beta_3 Y_{j3} + \beta_4(X_{i4}Y_{j4}) + \ldots + \varepsilon_i$

The probability of farm household *i* choosing improved variety *j*, Pr (E_{ij}), will be a function of the variables that define Z_{ij}, the characteristics included in vector Y_j and combinations of X_i interacted with Y_j. The format permits maximum likelihood estimates of β, and the probability of making any particular choice can be calculated using the conditional logit specification displayed in Eq. 21.4. To ensure model identification (Cameron and Trivedi 2010), β_j is set to zero for one of the categories, and coefficients are interpreted with respect to that category, called a base category. The results of this study are reported in the form of marginal effects. These are interpreted as the proportional change in the likelihood of farm household *i* choosing variety *j* for a unit increase in the variable, holding all other variables constant. Following Cameron and Trivedi (2010), if the alternative specific regressor can be denoted by Z_r with the coefficient β_r, the effect of change in Z_{rik}, which is the value of Y_r (or possibly interaction of Y with X) for farm household *i* and alternative *k*, is:

$$\partial P_{ij} / \partial Z_{rik} = \begin{cases} P_{ij}(1 - P_{ij})\beta_r & \text{IF} \quad j = k \\ -P_{ij}P_{ik}\beta_r & \text{IF} \quad j \neq k \end{cases} \tag{21.5}$$

If $\beta_r > 0$, the own-effect is positive because P_{ij} $(1 - P_{ij})$ $\beta_r > 0$, and the cross-effect is negative because $-P_{ij}P_{ik}\beta_r < 0$.

Materials and Methods

Six rice schemes, Bugarama, Rwasave, Mukunguli, Rusuri, Cyabayaga, and Cyaruhogo, were purposively selected (Table 21.1) with a total population of about 8,000 from which 180 households were randomly selected. Based on recommendations by Israel (1992) and referring to previous studies on the adoption of improved agricultural technology, a sample size of between 50 and 200 households provides sufficient data to make inferences (Feder et al. 1981; Upadhyaya et al. 1993; Omonona et al. 2006; Saka et al. 2005; Singh et al. 2006; Adewale et al. 2007; Edet and Borating 2008; Paudel and Matsuoka 2008). Descriptive statistics such as frequency distribution, means, and percentage were performed and an econometric approach using STATA (10) was used to estimate the adoption model.

Table 21.1 Distribution of respondents by rice schemes in Rwanda

Rice scheme	No. of farmers	Percentage of farmers
Bugarama	60	33.3
Mukunguri	42	23.3
Rusuri	15	8.3
Rwasave	15	8.3
Cyabayaga	24	13.3
Cyaruhogo	24	13.3
Total	**180**	**100**

Results

Socioeconomic Characteristics of Respondents

The results in Table 21.2 show that 80 % of adopters were male-headed households. For both adopters (84 %) and non-adopters (64 %), the majority had a primary level of education. Agriculture is the main economic activity for both groups. Adopters had more access to financial services than non-adopters.

Summary Statistics of the Characteristics of Adopters and Non-adopters

The findings in Table 21.3 indicate that the mean age of adopters and non-adopters is 41 years. The mean difference years of experience in rice farming between adopters (11 years) and non-adopters (6 years) is statistically significant ($P < 0.05$). The mean land size is 0.68 ha for adopters and 0.42 ha for non–adopters while the mean household size for both adopters and non-adopters is about 6. The mean number of dependents (children ≤ 15 years and adults > 65 years old) in the household is about 3 for both groups; the mean available labor within the farm household (adults between 16 and 65 years) is 1 for both groups.

Factors Influencing Adoption of Improved Rice Varieties

The response variable (adoption) was dichotomized with a value of 1 if the farmer has chosen at least one of the improved varieties out of six alternatives and 0 if otherwise. The specific attributes included in the model were seed price, paddy price, and variety yield. We further included in the model an interaction term of seed price and farm size as a variable that allows us to capture how seed price affects both small and large farmers. As it was not easy to find out the yield levels of the varieties that were not chosen, we used the multiple regression imputation

Table 21.2 Frequency distribution of farmers by socioeconomic characteristics

	Adopters = 141		Non-adopters = 39	
Characteristics	No. of farmers	% of farmers	No. of farmers	% of farmers
Sex				
Male	113	80.14	4	10.26
Female	28	19.86	35	89.74
Education level				
None	10	7.09	2	5.13
Primary	118	83.69	25	64.1
Junior high school	8	5.67	6	15.38
Senior high school	1	0.71	2	5.13
Tertiary	0	0	0	0.00
Other	4	2.84	4	10.26
Income sources				
Agriculture	119	84.40	35	89.74
Handicraft	3	2.13	1	2.56
Rearing	13	9.22	1	2.56
Processing	0	0.00	0	0
Commerce	3	2.13	1	2.56
Salaried	3	2.13	1	2.56
Access to financial credit				
Yes	79	56.03	8	20.51
No	62	43.97	31	79.4

Table 21.3 Mean distribution of farmers by socioeconomic characteristics

	Adopters = 141		Non-adopters = 39		Mean difference	
Variable	Mean	Standard deviation	Mean	Standard deviation	z	Prob > |z|
Age (years)	41.01	11.23	40.69	11.14	−0.211	ns
Sex	0.76	0.43	0.87	0.34	0.043	ns
Farm size (ha)	0.68	0.48	0.42	0.29	−0.672	ns
Experience in rice farming (years)	11.18	7.4	5.82	6.22	−2.459	s
Education	1.08	0.62	1.46	0.99	1.085	ns
Household size	6.13	2.0	6.36	2.06	−0.088	ns
Dependents ($\leq$15 and >65 years)	2.54	1.3	2.79	1.44	−0.224	ns
Available labor (>16 < 65 years)	0.87	0.86	1	0.86	−0.334	ns
Association membership	0.8	0.4	0.7	0.47	−0.713	ns
Access to extension services	0.65	0.48	0.68	0.47	0.58	ns
Access to financial services	0.55	0.5	0.33	0.48	−0.25	ns

ns not significant, *s* significant

method to generate these yield values. This is a procedure which replaces each missing value with two or more suitable values indicating a distribution of likely values (Rubin 1996). For farmers' characteristics, we used farm size, labor availability in a farm household, and access to financial services. The findings in

Table 21.4 Conditional Logit Model estimates

Choice	Coefficients	Standard error	Z	P > lzl
Variety				
Seed price	−0.0227	.0084265	−2.70	0.007
Paddy price	.0104023	.0056685	1.84	0.066
Yield	.0010309	.0005995	1.72	0.086
Seed price × farm size	.0096381	.0114177	0.84	0.399
Nerica				
Farm size	1.393716	4.054474	0.34	0.731
Dependents	−.1438974	.3422328	−0.42	0.674
Labor availability	.4817432	.5753882	0.84	0.402
Access to finance	14.97789	584.2387	0.03	0.980
_cons	−12.87449	584.2489	−0.02	0.982
Tox 4331-Wat91-3-1-1-1 (Gakire)				
Farm size	1.929954	1.707349	1.13	0.258
Dependents	1691042	.2194164	0.77	0.441
Labor availability	.0584944	.4429356	0.13	0.895
Access to finance	−.6219405-	.7816201	−0.80	0.426
_cons	−3.802086	1.580094	−2.41	0.016
Tox 4331-Wat86-3-4-2-1 (Intsinzi)				
Farm size	.5747421	1.481102	0.39	0.698
Dependents	−.3199945	.2703199	−1.18	0.237
Labor availability	.8843982	.5207807	1.70	0.089
Access to finance	2.420606	.8980094	2.70	0.007
_cons	−2.191288	1.62126	−1.35	0.177
Wat 1395-B-24-2 (Intsindagirabigega)				
Farm size	1.414725	1.391561	1.02	0.309
Dependents	−.0913617	.2295385	−0.40	0.691
Labor availability	.529218	.4072005	1.30	0.194
Access to finance	−.1118784	.7383923	−0.15	0.880
_cons	−2.000828	1.276363	−1.57	0.117
Wat 54-TGR-1-5 (Muturage)				
Farm size	4.002183	2.560735	1.56	0.118
Dependents	−.2257503	.2085702	−1.08	0.279
Labor availability	.4315923	.3769069	1.15	0.252
Access to finance	1.145465	.6604611	1.73	0.083
_cons	−6.256281	2.043022	−3.06	0.002

Number of observations = 1,080
Number of cases = 180
Log likelihood = −155.74115
Wald $\text{chi}^2(24) = 63.28$
Prob > $\text{chi}^2 = 0.0000$

Facagro (base alternative); *Note*: the names in brackets are local names of varieties

Table 21.4 indicate that seed price, paddy price, variety yield, farm size, labor availability, and access to financial services are highly, jointly, statistically significant with Wald chi^2 (22) = 63.28 and the model is correctly predicted at 86.8 %. Coefficients of the variables are statistically significant with the expected signs, seed price (−), paddy price (+), and yield (+).

We further estimated the marginal effects to explore the extent to which changes in explanatory variables affect the probability of farmers' choices between different alternatives.

The results in Table 21.5 show that a one unit increase in the price of seeds decreases the likelihood of choosing varieties *Facagro*, *Tox 4331-Wat91-3-1-1-1*, *Tox 4331-Wat86-3-4-2-1*, *Wat 1395-B-24-2*, and *Wat 54-TGR-1-5*, ranging from .001 to .004. The same results show that a one unit increase in the price of paddy increases the likelihood of choosing varieties *Facagro*, *Tox 4331-Wat91-3-1-1-1*, *Tox 4331-Wat86-3-4-2-1*, *Wat 1395-B-24-2*, and *Wat 54-TGR-1-5*, ranging from .001 to .003. In addition, we observe that a one unit increase in the yield of varieties *Facagro*, *Tox 4331-Wat91-3-1-1-1, Tox 4331-Wat86-3-4-2-1, Wat 1395-B-24-2*, and *Wat 54-TGR-1-5* increases the probabilities of these varieties being chosen, ranging from .0001 to .0003. The above results suggest that the effects of change in seed price, paddy price, and yield for the variety *Wat 54-TGR-1-5* are higher than for other alternatives.

Furthermore, the results show that a one unit increase in farm size decreases the likelihood of choosing varieties *Facagro, Tox 4331-Wat91-3-1-1-1*, *Tox 4331-Wat86-3-4-2-1*, and *Wat 1395-B-24-2,* ranging from .04 to .3, while it increases by .42. The likelihood of choosing alternative *Wat 54-TGR-1-5*. We also observe that a one percent increase in access to financial services decreases by .14 the likelihood of choosing alternative *Tox 4331-Wat91-3-1-1-1* and increases by.20 the likelihood of choosing alternative *Wat 54-TGR-1-5*.

Discussion

The negative coefficient of the variable seed price means that if the price of seed increases by one unit for the base alternative (*Facagro* variety), the demand for this variety decreases by −.0223 in favor of the demand for other alternatives, ceteris paribus. The positive coefficient of the variable paddy price indicates that if the price of the base alternative increases by one unit, the demand for this alternative increases by .0104 and the demand for other alternatives decreases. The positive coefficient of the variable yield means that if the yield of the base alternative increases by one unit, the demand for this variety increases by .0010 with a subsequent decrease for other alternatives. The positive coefficient of .0096 of the variable seed price × farm means that the seed price does not matter for larger farmers. This is explained by the fact that larger farmers have capital and access to financial services in terms of own savings or credit; thus, they can even afford the seed price better than smaller farmers.

Coefficients of variables farm size, dependents, labor availability, and access to finance indicate that these variables are also important factors that influence the farmers' choice among improved varieties. All the coefficients of the variable farm size are positive, meaning that, relative to the probability of choosing an alternative to *Facagro*, the bigger the size of the farm, the more likely farmers are to choose

Table 21.5 Marginal effects

Alternative	Variable	Marginal effects	Standards error	z	P-value
Facagro	Seedprice	−0.002766	0.000886	−3.12	0.002
	Paddyprice	0.001733	0.000886	1.76	0.078
	Yield	0.000174	0.000101	1.72	0.086
	Farmsize	−0.267807	0.185817	−1.44	0.150
	Dependents	0.022287	0.028403	0.78	0.433
	Laboravailability	−0.067443	0.053488	−1.26	0.207
	Accessfinance	−0.106453	0.083477	−1.28	0.202
Nerica	Seedprice	−0.0000014	0.000386	−0.00	0.997
	Paddyprice	0.00000085	0.000242	−0.00	0.997
	Yield	0.000000085	0.000024	−0.00	0.997
	Farmsize	0.000247	0.070525	0.00	0.997
	Dependents	−0.0000039	0.001099	−0.00	0.997
	Labouravailability	0.000014	0.004014	0.00	0.997
	Accessfinance	0.07368	0.048003	1.53	0.125
Tox 4331-Wat91-3-1-1-1	Seedprice	−0.001865	0.000722	−2.58	0.01
	Paddyprice	0.001205	0.000704	1.67	0.095
	Yield	0.000117	0.000074	1.59	0.112
	Farmsize	−0.048232	0.118005	−0.41	0.683
	Dependents	0.034568	0.020753	1.67	0.096
	Laboravailability	−0.034245	0.040269	−0.85	0.395
	Accessfinance	−0.142195	0.070312	−2.02	0.043
Tox 4331-Wat86-3-4-2-1	Seedprice	−0.000839	0.000311	−2.7	0.007
	Paddyprice	0.000525	0.000358	1.47	0.143
	Yield	0.000053	0.000038	1.37	0.170
	Farmsize	−0.057046	0.065582	−0.87	0.384
	Dependents	−0.01146	0.013164	−0.87	0.384
	Laboravailability	0.030833	0.02164	1.42	0.154
	Accessfinance	0.098738	0.052193	1.89	0.059
Wat 1395-B-24-2	Seedprice	−0.002561	0.00075	−3.41	0.001
	Paddyprice	0.001604	0.000919	1.75	0.081
	Yield	0.000161	0.000097	1.65	0.099
	Farmsize	−0.044882	0.16488	−0.27	0.785
	Dependents	0.002621	0.028763	0.09	0.927
	Laboravailability	0.033916	0.0463	0.73	0.464
	Accessfinance	−0.124412	0.085162	−1.46	0.144
Wat 54-TGR-1-5	Seedprice	−0.004118	0.00102	−4.04	0.000
	Paddyprice	0.00258	0.001403	1.84	0.066
	Yield	0.000259	0.000147	1.76	0.079
	Farmsize	0.417719	0.300873	1.39	0.165
	Dependents	−0.048012	0.039801	−1.21	0.228
	Laboravailability	0.036925	0.064176	0.58	0.565
	Accessfinance	0.200642	0.112325	1.79	0.074

other varieties, ceteris paribus. The *Facagro* is less preferred by farmers because of its lower yield compared with other varieties. Furthermore, the variety is reported to be more susceptible to disease. The relationship between farm size and choice probabilities of improved rice varieties was also found in India where a unit increase in farm size was associated with 5 % increase in the proportion of area planted with improved varieties, such as Basmati (Singh et al. 2006).

The relationship between farm size and alternative choices indicated that farmers with bigger farms are more likely to adopt or extend the proportion of land planted with higher yielding alternatives than farmers with small farms. This is explained by the fact that these farmers are mostly commercially oriented. Saka et al. (2005) found that the choice of high yielding rice varieties in Nigeria is determined by the farm size, among other factors.

The negative relationship between variable dependents and adoption (except for the variety *Tox 4331-Wat 91-3-1-1*) means that as the number of dependents increases (translating this as a shortage of labor) in the farm household, farmers are more likely to choose the varieties of *Facagro* and *Tox 4331-Wat 91-3-1-1*. Furthermore, farm households with more active members are more likely to adopt varieties other than *Facagro* as it is indicated by the positive coefficients of the variable labor availability (translating this as the availability of labor in a farm household). These results suggest that the *Facagro* variety, although lower yielding, is less labor demanding.

The positive relationship between the adoption of varieties of *Nerica, Tox 4331-Wat 86-3-4-2-1, Wat 1395-B-24-2*, and *Wat 54-TGR-1-5* and access to financial services means that as their access to credit facilities increases, farmers are more likely to choose these varieties than *Facagro*. The negative relationship between choice of varieties of *Tox 4331-Wat 91-3-1-1-1* and *Wat 1395-B-24-2* and access to financial services means that farmers would prefer *Facagro* to these varieties when their access to credit facilities is increased. Edet and Borating (2008) found the same relationship between access to credit and the adoption of improved rice varieties and concluded that access to financial services increased the likelihood of the adoption by 0.1831 in Nigeria.

The negative own seed price effects mean that if the seed price of a variety increases, the likelihood decreases that the variety will be chosen and increases for other alternatives. In addition, the positive own paddy price effects indicate that if the paddy price increases for a variety, the likelihood increases that the alternative will be chosen and decreases for other alternatives. The same applies for own yield effect meaning that if the yield of a variety increases, the likelihood increases that the variety will be chosen and decreases for other alternatives.

Conclusion

In Rwanda, there is a high rate of adoption of improved rice varieties due to the high level of acceptance of these varieties among rice farmers as they generate higher economic benefits than local varieties. Seed price, paddy price, and variety yield are variety attributes; farm size, labor, and access to financial services are farm household characteristics that statistically and significantly influence farmers' decisions to adopt improved varieties. Future policy should focus on improving input supply systems and incentives through crop prices.

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Chapter 22

Assessing the Influence of Farmers' Field Schools and Market Links on Investments in Soil Fertility Management Under Potato Production in Uganda

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Abstract Exploring the synergy of Farmer Field Schools (FFSs) and profitable market links on agricultural production is important in enhancing adoption of improved Soil Fertility Management (SFM) innovations in smallholder farming systems. A comparison study was conducted in the highlands of southwestern Uganda with communities with and without FFSs having urban and local potato market links respectively. While it is widely perceived that the FFS approach is experiential learning among farmers and may lead to adoption of improved beneficial innovations, potato farmers in the highlands of southwestern Uganda invested less towards improving soil fertility. Furthermore, linking farmers to improved markets did not necessarily lead to adequate investment in improved SFM in potato production. This led to continuous soil mining and subsequent negative nutrient flow balances in most potato fields belonging to households of the different wealth categories. Positive nutrient flow balances of some fields resulted in reduced tuber yields due to infection of bacterial wilt, leading to reduced nutrient outflows from potato fields.

Keywords Farmer field schools • Market links • Soil fertility • Potato • Nutrient flow balances

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Introduction

Advances in agricultural production techniques (Kelly 2006) have stimulated an average annual growth in global per capita consumption of 0.3 % (Southgate 2009). However, in sub-Saharan Africa (SSA), reduced incentives to invest in agriculture has led to challenges of providing high quality and sufficient food to rising rural populations. This has led to considerable concern of food insecurity among the rural poor as the population continues to rise as compared to food supply (Okalebo et al. 2006). Therefore, there are constant pressures on agricultural extension services to respond to the growing challenges of food production. However, increases in crop productivity cannot be achieved without addressing the causes of land degradation (Gachene and Kimaru 2003). Agricultural extension systems that link research to farmers while delivering new innovations for improved agricultural production are considered outdated, inflexible, and a top-down approach of service delivery that has limited capacity to cope with the ever changing demand of agricultural production (Rivera et al. 2000). Thus, decline in per capita food production is intrinsically linked to degradation of the natural resource base, increasing population pressure, overstretched extension services, and poor farmer–market links among other factors (Hilhorst and Muchena 2000). The pressure to change in agricultural service delivery that has been exacerbated by structural adjustment programs in Uganda and other countries in SSA and has led to the traditional agricultural extension system being inappropriate.

Many countries in SSA are currently using the Farmer Field School (FFS) approach in delivering agricultural services to farmers. The FFS is a popular extension and education program known worldwide (Braun et al. 2006). It started in Indonesia in 1989 and expanded through many countries in SSA. This approach to extension education has been embraced by a number of donor, government, and nongovernmental organizations that enthusiastically promote agricultural innovations in SSA today. The FFS approach has -the potential of being scaled out and incorporated into mainstream extension practices in countries of SSA (Anandajayasekeram et al. 2007).

Through the FFS approach, there is participatory learning using technology development and information dissemination based on adult learning principles. Groups of 20–25 farmers typically meet every week in an informal setting in their own environment. Farmers are enabled to conduct their own research, diagnose and test problems, and come up with appropriate solutions. Here, farmers carry out experiential learning activities following specific curricula that help them understand their environment and the ecology of a particular crop grown. Among the activities involved in the FFS are simple experiments and regular field visits to collect the necessary data on particular parameters agreed upon. Experience gained from these processes empowers farmers to come up with the right decisions in crop management.

However, to sustain agricultural production and household income among smallholder farms, donors, governments, and nongovernmental organizations in SSA are advocating for improved farmer–market links. Over 80 % of the farmers in SSA are subsistence farmers using rudimentary technologies in crop production and lack a proper market for agricultural produce (Amanor-Boadu 2007). For example, farmers in the highlands of southwestern Uganda traditionally produce (using low input technologies) and sell ungraded, mixed potato varieties at farmgate prices. They are poorly organized with limited postharvest storage facilities. This has made them sell potato harvest at low prices, more especially at the peaks of harvest. This in turn has given farmers an incentive to invest in improved soil fertility management innovations to sustain potato production.

Rapid urban population and expansion of urban centers in Uganda has led to changes in feeding habits, which has created new market opportunities for potato farmers. Such new market opportunities include fast-food restaurants and a chain of supermarkets. There is evidence that food markets in Uganda are undergoing restructuring through consolidation and embracing foreign investment. Through restructuring, there is a steady disappearance of market agents and farmers are given an opportunity to interact with the final buyer, who in turn supplies to final consumers. With this market restructuring, farmers are given contracts to supply their produce in the required quantity and quality to enable them to have a steady and regular income all year round.

In order to maintain a steady supply through sustained potato production, farmers in the highlands of southwestern Uganda were trained in the use of improved soil fertility management innovations using the FFS approach. Farmers' participation in FFSs took 3 years to complete the outlined curriculum and perfect potato production in individual fields. Where there was improved potato production, farmers were linked to fast-food restaurants and other markets in the value chain and sold at higher prices compared to farmgate prices. Farmers went into contracts with fast-food restaurant owners to supply 10 t of potato a month. The contract terms were renegotiated at the end of every year to cater for inflation and agricultural input prices. These farmers were able to do so with the support of research and development agencies as well as their own efforts to invest in improved agricultural production.

This paper examines the influence of integrating the FFS approach and market links in potato production to combat land degradation in the highlands of southwestern Uganda. Two communities with and without FFSs and contrasting market links were compared in levels of investing in nutrient management innovations in potato agro enterprises. Furthermore, major nutrient flow balances (N, P, K, and Mg) in potato fields belonging to households of different wealth categories were assessed.

Methodology

Study Site

The study was conducted in Kamungaguzi sub-county, Kabale district, located in the highlands of southwestern Uganda. The district has a montane type of climate with an annual rainfall of 800–1,000 mm. The long rains occur between

Table 22.1 Farmers' perceptions on soil rating and land use on landscape

Map unit	Land-form	Soil fertility	Soil depth	Estimated soil depth (cm)	Major land use
1	Hilltops	Extremely low	Shallow	30	Woodlots, potato, and beans
2	Shoulders	Extremely low	Very shallow	10	Woodlots, potato, and beans
3	Back slopes	Very low	Shallow	15–20	Potato and beans
4	Foot slopes	Low	Fairly deep	50–80	Potato and beans
5	Valley bottoms	Medium/good	Deep	>100	Potato and grazing

mid-August and December, followed by short rains in mid-March and May; and a short dry spell between June and July (Carswell 2000). Subsequently, Kabale is food self-sufficient, although the soils have gradually been losing fertility due to soil erosion and lack of resources for soil fertility management innovations (Kazoora 2002).

Kamuganguzi sub-county is situated at 1° 21′ 0″ S and 30° 1′ 0.12″ E and lies over 2,000 m above sea level. It has potato farmers with different market links and it is representative of the surrounding areas in terms of topography and land use. The slopes are steep, with numerous ridges and cones, with high erosion potential and shallow, dark brown soils of low productivity. Most of the landscape (75 %) is intensively cultivated with a few fields under fallow. The valley bottoms are mainly constituted of deep humus, brown loamy soils with moderate to high productivity. Fragmentation of landholdings is severe and the average landholding is about 0.32 ha per household (NEMA 2001). In a radius of 7 km, the population density is 144 persons/km^2.

Research Approach

Six parishes in Kamuganguzi sub-county were selected based on their common biophysical features and characteristics such as slope gradient, soil fertility and depth, and farming characteristics. Transect walks following the diagonal section of the slope were conducted from the valleys to hilltops in communities with and without FFSs to assess soil characteristics (depth and fertility levels) and major crops cultivated on different slope positions as perceived by farmers (Table 22.1). Gradients of the different slope positions were determined with the help of clinometers.

Two communities were formed: (1) a community with FFSs composed of Katenga, Kicumbi, and Buranga parishes that were trained using the FFS approach in the use of improved SFM innovations in potato production and linked to urban markets; and (2) a community without FFSs composed of Kasheregyenyi, Mayengo, and Kyasano parishes that never had any training using the FFS approach and sold potato to local markets. The community with FFSs had 125 members under small groups composed of 20–25 members who would meet and train in various aspects of potato production (seed selection and production, disease management, and SFM). These FFSs were led by experienced farmers under close supervision from trained personnel from a development agency (Africare) and a research institute (National Agricultural Research Organization – NARO). The curriculum followed in farmer-run FFSs was developed by participating farmers with the help of facilitators from Africare and NARO who met the farmers once a week.

Farmers in FFSs conducted field experiments after identifying a problem that required a solution and this was done on volunteer farmers' fields. Periodic monitoring and evaluation of the experiments was done and promising innovations taken up by farmers on their individual potato fields. This kind of training and participatory research in potato production using improved agricultural innovations took 3 years for farmers to get adequate knowledge.

The same farmers in FFSs were trained in marketing and negotiation skills. During participatory market surveys that were conducted within the district, city, and neighboring urban centers, potential potato buyers were identified. Market requirements were analyzed and farmers identified the fast-food restaurant owner (NANDOS) as the most suitable to be supplied with potato through contract farming. They supplied 10 t of potato once a month and the terms of the contract were re-visited at the end of every year, depending on the prevailing market conditions such as inflation and costs of agricultural inputs (chemicals and seed). When this study was undertaken, farmers had supplied potato for 5 consecutive years and had started linking to other market outlets.

To analyze socioeconomic conditions of potato farmers in communities with and without FFSs, key informants comprising community leaders, elders, and experienced farmers in each parish were identified to generate lists of households in different wealth categories (WCs). During focus group discussions, indicators of WCs were developed and ranked by farmers using their own criteria (Table 22.2).

Rapid farm surveys for all the WCs were conducted using a sample of 30 households per parish (180 households in all parishes). The survey was used in conjunction with field walks to confirm or relocate the households in the correct WCs. Five households growing potato for the market in each WC per community were randomly selected for detailed farm studies involving nutrient flows that were conducted for two seasons. Field typologies for potato were developed based on their distances from homesteads and positions on the landscape. Soil samples were obtained at a depth of 0–15 cm from individual potato fields and analyzed for physical and chemical properties following procedures described by Okalebo et al. (2002).

At the beginning and middle of the cropping seasons, nutrient-management options farmers used were noted. Organic amendments were sampled and analyzed for nutrient content. Households were visited again at the end of the growing season to assess potato yields. Tuber yields were estimated from micro-fields demarcated

Table 22.2 Wealth categories as perceived by farmers

The rich (WC I)	**Middle WC II**
Had a permanent house	Had a good but semi-permanent house
Had at least one vehicle	Had a bicycle
Had at least UGX 3,000,000 (US$1,200)	Had at least UGX 200,000 (US$80)
Had at least 15 plots	Had at least 10 plots of land
Had at least 10 goats	Had at least five goats
Had educated children	Had educated children
Harvested at least 24 t of potato per season	Harvested at least 4.8 t of potato per season
Had at least four improved cows	Had at least one exotic cow
Had at least three woodlots	Had at least two woodlots
Hired at least 30 farm workers per year	Hired at least five farm workers a year
Had three meals a day	Had two meals a day
Poor (WC III)	**Poorest (WC IV)**
Had grass thatched house	Had small and poor grass thatched house
Had children in Universal Primary Education	Could not educate their children
Had at least one goat	Had no livestock
Had at least two plots of land	Had only one small plot around the house
At times provided labor for food	Provided labor for food
Had one meal a day (eat late lunch)	Could not afford good clothes

in main fields. At the field level, the residues from the field incorporated into the soil were considered as internal flows and not used in the calculations of nutrient flow balances. Nutrients removed from the potato field in form of crop residues were considered as out flows. Similarly, nutrients brought to the potato fields from outside were considered as external inflows. Nutrient flow balances were presented on a hectare (kg/ha) by subtracting total N, P, K, and Mg removed in tubers and residues from total N, P, K, and Mg in inputs (Eqs. 22.1 and 22.2).

$$P_{nut}\,bal\left(kg\;\;plot^{-1}\right) = \sum removed\,nutrients - \sum added\,nutrients \tag{22.1}$$

$$\begin{aligned} P_{nut}\,bal\left(kg\;\;hh^{-1}\right) = {} & \sum removed\,nutrients\,from\,all\,plots \\ & - \sum added\,nutrients\,in\,all\,plots \end{aligned} \tag{22.2}$$

where

$P_{nutrient}\,bal$ = Partial nutrient balance, hh = household

Statistical Analyses

Data obtained from household surveys was analyzed using the Statistical Package for Social Scientists (SPSS). Descriptive statistics and associations for socioeconomic data were used. Soil characteristics (physical and chemical properties) and nutrient flow data were entered and managed in Excel spreadsheets and later analyzed using an ANOVA table in the GenStat computer package. Interactions of the different parameters were determined and Fisher's LSD test was used to compare each pair of parameters analyzed using One-Way ANOVA (Analysis of variance).

Results and Discussion

Broad Socioeconomic Characterization of Communities

There were 242 and 288 households in communities with and without FFSs, respectively (Table 22.3), with slightly more male-headed households in non-FFSs (about 78 %) compared to FFSs (about 70 %) communities. Non-FFS communities were located at the Katuna border with Rwanda, with more men engaged in cross-border business than agricultural production. Cross-border business was an alternative source of household income and restricted household members in their movements. Members in non-FFS communities commuted from homes to their business premises such as shops, markets, or roadside stalls. Some of them were engaged in money exchange businesses, targeting travelers going to and from Rwanda.

The number of male-headed households was weakly correlated with exposure to FFSs ($R = -0.110$, $P = 0.011$), though farmers were trained to produce more potato from the limited land resources. Some men in communities with FFSs migrated to other communities or distant districts to look for other paying jobs due to reduced land productivity. For households with husbands not at home, wives and children continued cultivating agricultural land even when its productivity had declined. This situation was similar to what Nkonya (2002) reported that some farmers switch to off-farm activities as a response to declining per capita farm output and environmental stress. Female-headed households comprised widows, single mothers, wives with husbands working far away from their communities, or wives abandoned by their husbands.

Table 22.3 Broad characterization of households in the study area

Characteristics (%)	FFS (n = 242)	Non-FFS (n = 288)	Chi-square	Pearson correlation	Asymp. sig
Male headed households	69.8	77.8	6.527	−0.110	0.011
Potato growers	41.3	47.9	1.004	0.043	0.316
Wealth Category I	4.1	3.5	25.037	0.182	0.000
Wealth Category II	36.0	18.1			
Wealth category III	47.5	58.7			
Wealth Category IV	12.4	18.8			

There was a weak relationship ($R = 0.043$, $P > 0.05$) between the number of households engaged in potato production and exposure to FFSs because potato was both a cash and food crop for all communities; hence, almost an equal number of households engaged in potato production. However, a significant portion of households was composed of non-potato growers, with 58.7 % (FFS) and 52.1 % (non-FFS) irrespective of FFS presence; this was attributed to prohibitive production costs coupled with high a prevalence of diseases such as bacterial wilt (BW). Inputs such as seed potato (US$29–88 per 80-kg bag), fertilizer (US$77–88 for a 50-kg bag of NPK), and fungicides (US$21–41 per kg) were too costly for most farmers. Most households in WC I (4.1 % in FFS and 3.5 % in non-FFS communities) and WC II (28.5 % in FFS and 18.1 % in non-FFS communities) were male-headed, indicating that most female-headed households had limited resources and were in WCs III and IV. Most households in WCs III and IV had neither permanent nor semi-permanent main houses. Households in such WCs with permanent or semi-permanent main houses were previously rich but when supportive family members who were mainly male heads died, the wellbeing of the survivors deteriorated.

Children of school age belonging to households in WC IV received no education, including that offered in universal primary schools, due to lack of basic materials such as books, pens, and pencils. In FGDs, children from such households showed symptoms of malnutrition as earlier reported in other studies (Alacho et al. 2000). Beans were rare in such households, yet they could be used as a protein source. Furthermore, such households had few meals per day and offered casual labor as a coping mechanism to avert food scarcity.

In contrast, households in WC I possessed sums of money in excess of US$1,000 saved in banks and had more animals compared to other households. They could afford several meals a day and often incorporated sources of proteins in their diets. Most households in WC I had bicycles or vehicles. Such households owned several fields, including those rented, and could afford to open them up, sometimes using hired labor.

Soil Physical and Chemical Properties of Potato Fields

Soils in potato fields in all communities with and without FFSs were clay loam in texture and were very heavy due to soil erosion, thereby exposing the sub-soil with a high clay content (Table 22.4). The high soil density and shallow depth resulted in shallow extension of the rooting system into the soil profile in an effort to explore and find water and nutrients (Place et al. 2008). Sub-soils are known for poor internal drainage, poor soil structure, and low organic matter content. Erosion usually reduces the percentage of macro pores that in turn reduce soil aeration and the amounts of water infiltrating into the soil. In some areas, farmers' fields were severely degraded with little chance of being rehabilitated due to poor agricultural practices used such as cultivation of steep slopes without soil

Table 22.4 Variation of soil properties in communities with and without FFSs

		Sand	Clay	Silt		Ca	Mg	K	P	SOC[a]	Total N
Location	Bulky density g/cm^3	(%)			pH	(mg/kg)				(g/kg)	
FFS	1.88	48.7	26.74	24.61	5.6	1,093	260.3	197.8	41.4	19.2	1.5
Non-FFS	1.86	37.3	33.25	29.48	5.9	1,167	274.2	278.4	47.7	14.9	1.1
LSD	ns	7.73	5.12	4.20	ns	ns	ns	ns	ns	0.003	0.03
CV (%)	24.15	31.24	28.76	26.25	13.62	54.36	56.07	125.56	201.34	34.4	42.0

[a] *SOC* soil organic carbon

Table 22.5 Variation in use of soil amendments with tuber yields

	Manures (t/ha)		Fertilizer NPK (kg/ha)	
Plot location	FFS	Non-FFS	FFS	Non-FFS
Hilltop + homestead	1.33	0.00	242	190
Hilltop – homestead	0.00	0.00	164	46
Mid slope + homestead	0.35	0.16	45	72
Mid slope – homestead	0.00	0.38	45	23
Valley + homestead	0.00	0.56	0	5
Valley – homestead	0.00	0.00	77	0
LSD	0.735	ns	ns	105.0
S.E.	0.837	0.640	399.9	66.6

conservation measures (NEMA 2001). Due to the poor soil conditions, the average yield of most fields was in the range of 5–7 t/ha compared to on-station yields of 20–40 t/ha.

Exchangeable Ca and Mg were in the medium and high range, respectively. Exchangeable K was in the range of medium to high, a favorable condition for potato growth (Darwish et al. 2004). However, due to high clay levels resulting from high levels of weathering, there were possibilities of P and K fixation, more especially at low soil moisture content (Barry and Merfield 2008) observed in dry spells.

The soils were moderately acidic. There was a significant difference in total soil organic carbon (SOC) and nitrogen (N) in potato fields in communities with and without FFSs. Potato farmers in communities with FFSs cultivated potato, mostly around homesteads that are more accessible, with organic waste such as farmyard manure and household waste. Nonetheless, the amount and quality of organic waste added to the soil could supply sufficient nitrogen and other nutrients to support high potato yields. Soil N was therefore low and yet it is the dominant nutrient taken up by potato. Low N availability has negative effects on potato growth (McCown and Kass 2008). Potato is generally regarded as an inefficient user of N and its shallow rooting system fails to adequately exploit soil N (Gastal and Lemaire 2002). Extractable P was high and therefore adequate for potato production. Potato does not need P as much as K and N (Darwish et al. 2004). Due to poor soil conditions, innovations in addition to fertilizer amendments that favor greater potato root penetration to exploit soil water and nutrients are required for higher yields.

Variation of Soil Inputs with Field Typologies

Potato fields located near homesteads had a higher likelihood of receiving soil fertility improvement innovations in the form of farmyard manure or fertilizers (Table 22.5). Nonetheless, the amount of manure applied was inadequate to supply sufficient nutrients as well as improve soil physical conditions in both communities with and without FFSs.

While farmyard manure is an excellent source of organic matter and is commonly applied in mixed farming systems, its nutrient content is quite low (Okalebo et al. 2006). The quality of farmyard manure largely depends on the type of animal, quality of feeds, quality and amount of bedding used, storage of manure, and how it is applied (UWS et al. 2008). Most farmers had small ruminants such as goats and sheep that were fed on rough pastures and crop residues such as sorghum stover that contained insufficient nutrients. Exposure of these manures to rain and sunshine also led to nutrient loss through leaching and volatilization.

Potato farmers in communities with FFSs and proper market linkages applied higher rates of NPK fertilizers in fields located on hilltops to improve potato productivity. Hilltops are known to have soils of low fertility due to erosion and yet such areas produce high quality potato tubers with low water content and such potato can be stored for longer periods. Furthermore, hilltops are known to produce good seed potato due to low infestation with pathogens causing bacterial wilt of potato. Fields located on lower slopes and valley bottoms are known for higher infestations of BW, sometimes leading to yield losses of up to 100 %. These losses are a disincentive for farmers to invest in soil fertility management innovation through purchasing fertilizers. Most of the valley bottoms were generally drained wetlands with high levels of organic matter and therefore with high soil fertility. In such areas, very limited fertilizer was applied, except in heavily drained fields that were intensively and extensively cultivated throughout the year.

Nutrient Flow Balances as Affected by Market Links

Nutrient stocks in the cultivated soil are dynamic and linked to field's resource flows and capture (Bekunda and Manzi 2003). There were general negative nutrient flow balances for all nutrients in communities with and without FFSs. The balance was more negative for nitrogen and potassium in both communities due to the high demand of both nutrients by potato (Figs. 22.1 and 22.2). The high amounts of the two nutrients extracted from the soil are not comparable to the amounts added to the soil in the form of soil inputs (fertilizer and manure). There were negative nitrogen balances among all the WCs in both communities with and without FFSs. Nonetheless, higher negative nitrogen balances were found in potato fields for households in WCs I and II in communities with FFSs and proper urban market links.

While these households applied high levels of NPK fertilizers compared to other WCs, they extracted more NPK, leading to higher negative flow balances of the nutrients in the community. The low nutrient flow balances observed in the potato fields for poor resource households (WCs III and IV) was due to high levels of BW of potato that led to yield losses of sometimes up to 100 %. Incidences of BW were mostly observed in potato fields belonging to poor resource households in communities with FFSs and proper urban market links. Fields of such households are under

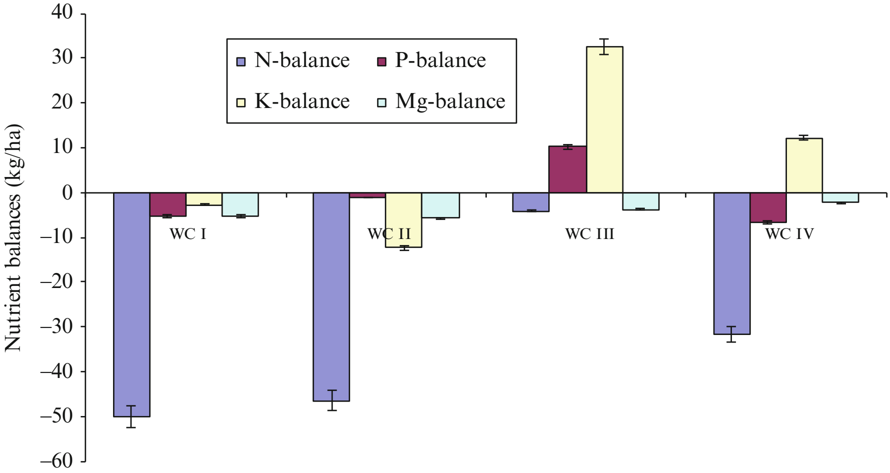

Fig. 22.1 Variation in nutrient flow balances in different household typologies in communities with FFSs

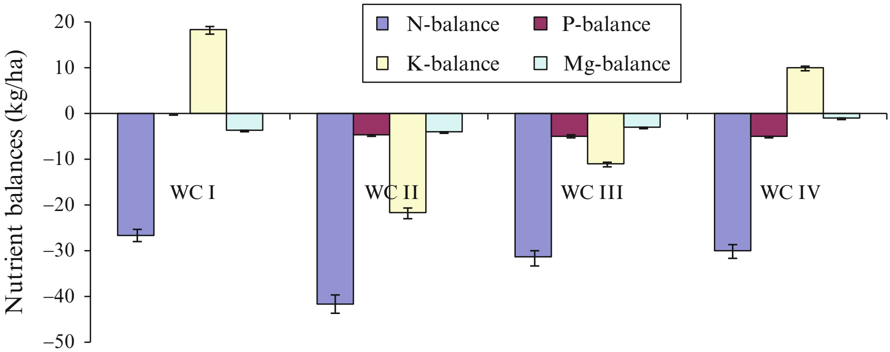

Fig. 22.2 Variation in nutrient flow balances with different household typologies in communities without FFSs

continuous cultivation with potato with no fallow periods to break the disease cycle. Potato fields in communities with FFSs and local markets are rotated with bush fallow and this breaks the disease cycle, hence reduces losses of potato tubers to BW.

Conclusions

While the FFS approach is widely conceptualized as one of the best approaches to extension for farmers in SSA to adopt improved agricultural innovations to sustain crop productivity, it was not beneficial with potato farmers in southwestern Uganda.

Potato farmers continued to degrade soils through continuous cultivation with minimal investments in improved SFM innovations. Potato fields located far from homesteads received less attention, leading to high soil degradation, more especially those located on upper slopes. Low investments in improved SFM innovations resulted into negative nutrient flow balances observed in most fields belonging to households of the different WCs. Positive nutrient flow balances observed in potato fields belonging to households of WCs III and IV were a result of infection with BW that led to low yields of potato. This resulted in less nutrient outflows from such potato fields. Hence, training of potato farmers in SFM using the FFS approach and linking them to profitable markets was not a guarantee to invest some of the proceeds into agricultural innovations that reduce soil degradation.

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Chapter 23
Bean Utilization and Commercialization in Great Lakes Region of Central Africa: The Case of Smallholder Farmers in Burundi

J. Ochieng, M.C. Niyuhire, C. Ruraduma, E. Birachi, and E. Ouma

Abstract Common bean (*Phaseolus vulgaris* L.) is a very important staple food crop in the Great Lakes region of Central Africa. Beans are a major source of food and revenue for smallholder farmers who make up the bulk of the poor population. The average per capita consumption of beans in Burundi of 60 kg/year is among the highest in the world. Beans play an important role but suffer from production constraints, poor efficiency of market systems and market knowledge, albeit undocumented. This study explores the utilization patterns of beans and examines factors influencing the commercialization of the crop in Burundi in order to provide valuable insights on how to improve the marketing system. Data were collected from a sample of 380 farmers obtained through multistage sampling technique. The production system for the common bean is characterized by low input, low output regimes, with a large proportion of the harvest being utilized for household consumption; thus remains limited marketable surplus. The seed sector in Burundi is dominated by the informal sector with more than half of the farmers using local seeds, a trend observed across all the provinces. The key determinants of bean commercialization include the quantity stored for food, the gender of the household head, education level, access to market through traders, and knowledge of bean network significantly influenced the commercialization of beans in

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smallholder systems. Therefore, to improve bean commercialization, interventions that increase farm productivity and foster commercial linkages between input suppliers, output buyers, and rural communities through market information systems should be emphasized. Continuous advocacy for seed policy change in Burundi to facilitate quick deliveries and linking farmers to output markets would enhance commercialization. Policy that encourages the industrial processing of beans is essential for increased food access and improved rural incomes.

Keywords Common beans • Utilization • Commercialization • Smallholder • Advocacy • Burundi

Introduction

Common bean (*Phaseolus vulgaris* L.) is a very important staple food crop in the Great Lakes region of Central Africa because of its nutritional value, and wide utilization at the household level as well as in industry. It is the first source of protein and micronutrients, particularly iron and zinc, for many family households. In addition, it is a major source of revenue to the smallholder farmers who are the bulk of the poor population. The average per capita consumption of beans in Burundi of 60 kg/year is among the highest in the world (FAOSTAT 2011). Consumption demand of beans in Burundi is expected to increase due to high population growth, lack of animal sources of protein, and the high prevalence of HIV/AIDS that necessitates an improved intake of protein to maintain good health. Despite the role beans play in economic growth, utilization of the crop in food and feed formulations has not been adequately exploited, compared with other countries such as Kenya, Tanzania, and Ethiopia. This implies that in the short term, efforts to promote common bean should focus on local utilization in food and animal feed formulations.

The major areas growing common bean in Burundi include Buyenzi, Kirimiro, Bugesera, Buragane, and Moso agroecological zones with yellow, red kidney, and white beans dominating the production system. In these zones, beans are intercropped with banana, maize, and other crops with limited monoculture. The report by FAOSTAT (2011) indicates that dry bean is the third most produced crop in Burundi after banana and sweetpotato. However, the growth of the bean subsector faces several production challenges. These include, in order of importance, unpredictable weather, pests and diseases, the high cost of new improved varieties, lack of capital, and lack of adequate land (Birachi et al. 2011).

Burundi has a high potential to increase production of beans per year but the potential has not yet been fully exploited despite the crop having been planted by farmers for decades. National bean production is still relatively low compared to other countries in the region as indicated in Fig. 23.1, although its wide ecological adaptation means that it can be produced throughout the country. The reasons for the underutilized potential of the dry bean are lack of reliable market and knowledge of farmers on processing and other utilization options (Birachi et al. 2011).

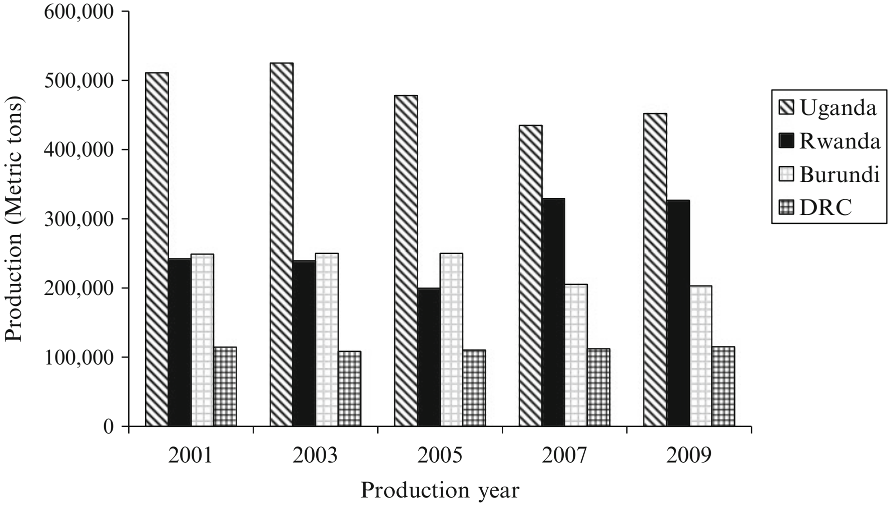

Fig. 23.1 National bean production across different countries (*Source:* FAOSTAT 2011)

The Institut des Sciences Agronomiques du Burundi (ISABU), in partnership with the Pan African Bean Alliance (PABRA) of the International Centre for Tropical Agriculture (CIAT), has been conducting research to produce common bean germplasm that is well adapted to the environment. In addition, there are other local and international organizations that promote bean production and commercialization among smallholder farmers in the country. These include the Department of Seeds and Plant Promotion (DSPP), the Provincial Directorate of Agriculture and Livestock (DPAE), PRASAB (World Bank) working with farmers' organization, and LVIA (Italian NGO) involved in seed dissemination and capacity building of smallholder farmers in the country. Other key players in the bean sector are FAO/CAU project, Catholic Relief Services (CRS), and the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), all working on intensification to increase productivity subsequently addressing poverty and challenges of food insecurity.

There are production and commercialization constraints that prevent smallholder farmers in Burundi from effectively utilizing the beans to meet their expectations especially with regard to household food and income security. Commercialization and improved market access are critical for improving rural farm incomes and household food security. Smallholder commercialization is highly influenced by factors of production as well as transaction costs. Transaction costs theory is derived from New Institutional Economics (NIE) which focuses on institutions of governance such as market and hierarchical modes of contracts and effects of exchange of goods and services. Key et al. (2000) and Ouma et al. (2010) have alluded to the fact that high fixed and variable transaction costs are one of the key reasons for the failure of smallholder farmers to participate and supply the right quantity of produce to markets in developing countries.

Fixed transaction costs do not vary with the volume of output traded while variable ones are per unit costs of access to markets that vary with the volumes traded. Fixed transactions costs incurred by smallholders include market search costs, negotiation and bargaining costs, and screening and enforcement of contracts cost. Variable transaction costs are transportation costs and the time taken to deliver products to different market.

Efforts to improve market infrastructure make it easier for farmers to gain access to inputs which increases the level of commercialization and productivity of crop enterprises (Shilpi and Umali-Deininger 2008). Many smallholder farmers reside in remote agricultural areas with poor transport and market infrastructure that contribute further to higher transaction costs. The civil conflict in Burundi destroyed the basic transport infrastructure that affects the transfer of commodities from farms to destination markets. In addition, the lack of a reliable market information system often leads to the exploitation of farmers by middlemen or brokers discouraging farmers' involvement in bean marketing. This study therefore responds to the demand for information on bean utilization and the status of commercialization by stakeholders in the bean subsector in Burundi.

Methodology

Study Area

The study was conducted in the year 2010 in the Northern and Central regions of Burundi and covered six provinces: Muyinga, Rutana, Ngozi, Bubanza, Gitega, and Makamba. Beans are grown in eleven agroecological zones across low, intermediate, medium, and high altitudes (from 774 to 2,670 masl). In 2008, 205,196 tonnes (t) of common bean were produced (FAOSTAT 2011). In the last decade these provinces have witnessed declining production trends due to various production constraints including climate change challenges.

Sampling Procedure

A multi-stage stratified sampling procedure was used to select sampling units. In the first stage, purposive sampling was used to select two districts and two markets in each province covering the major bean producing areas. Simple random sampling was used in the second stage to draw a sample of 380 smallholder farmers. The study mainly focused on smallholder farmers to capture their production, bean utilization, and marketing decisions.

Data Collection Procedure and Analysis

Primary data were collected from the smallholder farmers using structured interview schedules. The data comprised a range of issues including socioeconomic status of households, cropping and farming characteristics, bean utilization, production estimates, farm-gate and market prices, bean production and marketing constraints, and the nature of extension services. To achieve the objective of the study, key informants involved in the survey process included research institutions, agricultural projects, NGOs, and small-scale farmers. Descriptive statistics and simple linear regression analysis were carried out to summarize and interpret the responses collected. The data were processed and analyzed using Statistical Package for Social Scientists (SPSS) 18 version.

The Linear regression model was used to analyze factors influencing the quantity of beans marketed by smallholder farmers. Quantity marketed was used as a proxy of level of commercialization of beans at the farm level. The model establishes the relationship between a dependent variable and independent variables (Gujarati 2004) ranging from farm household, farm specific characteristics to consumption patterns. Ordinary Least Square (OLS) estimation procedure was used to estimate the model parameters. The econometric model for the quantity of beans marketed, a proxy for commercialization was estimated as shown in Eq. 23.1;

$$Y = \beta 1 + \beta 2X + u \tag{23.1}$$

Where;

$Y =$ quantity of beans marketed (kg/ha)
β_1 and β_2 represent the unknown non-random regression parameters and
X are the independent variables in the model
$\mu =$ random error.

Results and Discussion

The average household size was six members; the largest household had 15 members and the smallest only one person. In every household there was at least one adult woman and one man in both age brackets, below and above 65 years (Table 23.1). The average of three household members aged between 7 and 18 years is relatively high and they are likely not to be actively engaged in agricultural production and marketing activities. Most of the household members' ages ranged between 18 and 85 years with an average age of 43 years, an indication of availability of family labor Women form 25 % of household heads and this affects the household decision to sell produce since they have limited access to cash and labor resources.

About 16 % of farmers were members of groups; this figure is low compared with smallholder farmers in Kenya where over 50 % of farmers participate in

Table 23.1 Socioeconomic characteristics of the farm households

Variables	Mean	Standard deviation
Household size (number)	5.68	2.64
Adult men below 65 years	1.21	0.60
Adults women below 65 years	1.19	0.55
Adults over 65 years	1.51	1.04
Children between 7 and 18 years	2.78	1.55
Children below 7 years	2.07	0.93
Age of the household head (years)	43.3	14.2
Land allocated to bean (ha)	0.83	1.19
Distance to nearest market (km)	1.72	1.52
Gender (1 if female-headed)	0.25	0.02
Credit (1 if borrowed)	0.11	0.31
Extension (1 if received)	0.24	0.43
Group membership (1 if member)	0.16	0.37

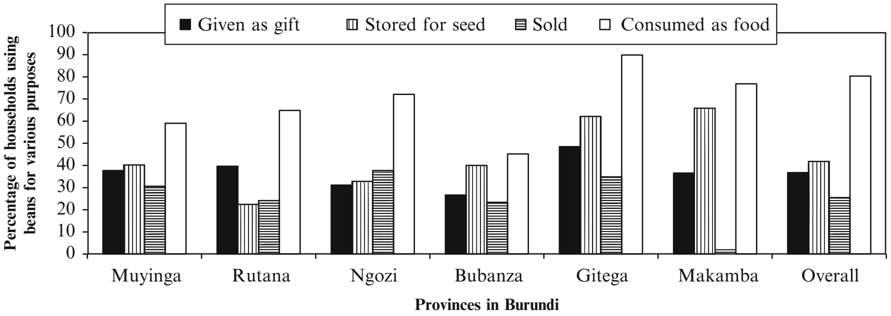

Fig. 23.2 Percentage of households using beans for various purposes in Burundi

collective action activities (Owuor et al. 2004; Ochieng et al. 2012). Farmers organized into groups benefit from increased access to extension; joint input purchases and group credit. Currently, only 11 % of smallholder farmers borrowed credit and 24 % received extension (Table 23.1). It is worth noting that access to formal credit has proved almost impossible for smallholder farmers; group-based lending is steadily becoming popular in Africa with a potential to improve household productive incomes by a range of between US$200 and US$260 in a single production period (Owour 2009). This, coupled with extension, would increase the farmers' purchasing power and willingness to buy inputs (such as fertilizers and new seeds) which subsequently increase production and commercialization.

Generally, smallholder farm households used most of the beans produced for food in all provinces (Fig. 23.2). This is a clear indication that many of them produce beans for subsistence rather than for commercialization purposes. In Ngozi Province, a large number of farmers (38 %) sold their output to the market, making them more market-oriented than the farmers in the rest of the provinces. Farm households prefer producing beans because all parts of the plant can be utilized: the grain is eaten fresh or dried and the leaves are used as vegetables. Bubanza and

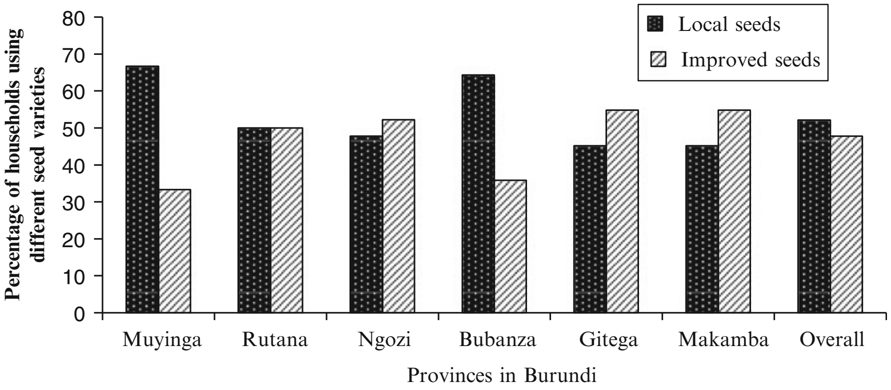

Fig. 23.3 Percentage of households using different seed varieties in Burundi

Makamba recorded the lowest proportion of farmers who supplied the market. These results are in line with the view that beans are a basic consumption commodity in Burundi as in many other countries in sub-Saharan Africa (SSA) where production levels are low. In areas such as Ngozi and Gitega Provinces where large quantities of beans are produced and has relatively higher commercialization levels.

Although beans are largely produced for subsistence, studies indicate that approximately over 40 % of production is marketed through retail markets, and formal and informal cross-border trade (Wortmann et al. 1999; Mauyo et al. 2007). This trend to participate in bean markets is highly influenced by factors of production, marketing and transactions costs including costs of searching for a trading partner, and costs of making and enforcing sale contracts. In Eastern and Southern Africa (ESA), the common bean is produced mainly for food and canning but the haulms and stalks are used for animal feeds or can be recycled as manure for crop production (Katungi et al. 2009). The situation is not different in Burundi where 70 – 80 % of output is used for domestic consumption. However, in Burundi, the industrial use of beans has not been exploited as compared with Ethiopia where damaged grains are processed into animal feed and production is historically meant for export with annual domestic per capita consumption ranging from 1 to 16 kg (Ferris and Kangazi 2008).

In general, more than half of the farmers in Burundi used local seeds (Fig. 23.3), a trend observed across the provinces except in Makamba, Gitega, Rutana, and Ngozi. Of the seven provinces, Muyinga Province recorded the highest number (over 65 %) of farmers that planted using local seed varieties. This could be because Muyinga is situated furthest, on the border with Tanzania, the region is not as highly productive as the rest and tends towards marginal areas. Thus distance to input sources (improved seeds especially from the research units) is a major factor here. It is also one of the new areas where bean projects are now focusing on increasing access to improved seeds. Gitega and Ngozi produce most of the beans in Burundi and at the same time rank the highest in bean consumption. The bean subsector in this region is taking a commercial dimension.

Often farmers prefer using improved seeds but most of the times do not use the recommended quantity of seeds as they are often out of reach in terms of cost and market availability. Farmers are familiar with improved bean varieties as they are easily available in the local markets and give higher yields than other local varieties (Chirwa et al. 2007). New planting materials prevent a more severe decline in yields from production constraints such as drought, low soil fertility, and bean root rot disease.

Factors Influencing Commercialization of Beans Among Smallholder Farmers in Burundi

The empirical results for factors influencing commercialization of beans are presented in Table 23.2. The F-test for the model was significant at 1 % indicating that the independent variables taken all together significantly explained the variation in the dependent variable at a 99 % confidence interval. This means that they influence decisions on bean commercialization made by smallholder farmers in Burundi. This also indicates fitness of the model that is the true slope coefficients were significantly different from zero. All the independent variables in the model were also tested for multi-collinearity as indicated by a variance inflation factor (VIF) of less than 10. The Durbin-Watson test had a value of 2.137, which is within the tolerable range of autocorrelation (Gujarati 2004). The significant factors were gender, education level, quantity of beans sold, quantity of beans stored for food and seeds, knowledge of the bean network, and market information received from traders.

The gender of the household head had a significant role in the commercialization of beans. Fewer female-headed households are likely to sell a larger proportion of produce compared with male-headed households. Women are often in control of the food management of the household; hence they are likely not to sell larger quantities of a staple food (such as beans) as they are more concerned with their family's food security. In addition, most female-headed households lack access to productive assets (land, labor, and capital) and this affects their marketable surplus (Ouma et al. 2010). On the other hand, the education of the household head as a decision-maker plays an important role in the level of commercialization of beans among smallholder farmers. Highly educated farmers possessed risk-takers behavior and were commercially motivated to sell beans for income generation. This result is in conformity with the findings of Karki and Bauer (2004) who find that higher education is an advantage for the adoption of farm innovations and helped farmers to conceptualize market information better than the less educated individuals.

The quantity of beans stored for food and seed was significant, showing that families storing less beans for food are able to supply more to the market.

Table 23.2 Factors influencing commercialization of beans in Burundi

Variables	Standardized coefficient	t-value	Sig. level
Constant	0.553	0.014	0.964
Age of the farmer (years)	−0.015	−0.444	0.658
Gender (1 if female household head)	−0.241	−1.740	0.085
Education level of household head (years)	0.051	1.872	0.063
Household size (#)	−0.022	−0.812	0.416
Total land allocated to bean (ha)	0.016	0.570	0.569
Group membership (1 if yes)	0.009	0.325	0.745
Extension contacts (1 if yes)	0.003	0.092	0.927
Did you borrow credit? (1 if yes)	−0.015	−0.564	0.573
Average market price for beans (BIF)	0.023	0.846	0.398
Quantity consumed at home (kg/ha)	0.010	0.384	0.701
Quantity of beans stored for seeds (kg/ha)	0.826	30.029	0.000
Quantity beans stored for food (kg/ha)	−0.105	−3.793	0.000
Quantity of beans given out as gifts (kg/ha)	−0.001	−0.047	0.963
Distance to nearest output market (km)	0.005	0.192	0.848
Access to infor. through traders (1 if yes)	0.073	2.683	0.008
Access to infor. through farmers (1 if yes)	0.016	0.539	0.590
Access to infor. through government (1 if yes)	−0.004	−0.152	0.879
Access to infor. through groups (1 if yes)	−0.011	−0.382	0.703
Quantity lost due to storage losses (kg/ha)	0.005	0.180	0.857
Quantity lost due transportation losses (kg/ha)	−0.153	−2.849	0.006
Do you know any bean network? (1 if yes)	0.044	1.789	0.093

Dependent variable: Quantity marketed/ha, a proxy for commercialization
DW 2.137; VIF: 1.1051; F-Statistic: 53.141; *P*-value 0.000
R^2 0.747; Adjusted R^2 0.733

This means that a 1 % increase in the quantity stored for food results in a reduction of 11 % in the commercialized surplus. The families supplying more to the market may have diversified into other sources of protein to reduce reliance on beans as the main source of proteins. As previously illustrated (Fig. 23.2) most farm households across the provinces produce beans for subsistence with less for sale.[1] Just as in Kenya, the demand for domestic consumption in Burundi exceeds domestic production thus the deficit is imported from neighboring countries such as Tanzania, Rwanda, and even Kenya. The transportation losses emerged as a major impediment to commercialization. The quantity of beans lost from transport ($P < 0.01$) translated into the inability of farmers to provide the desired quantity to the market. In the farming community in Burundi, the mode of transport is predominantly by bicycle (32 %) and human head-load (33 %) and this leads to higher transport losses such as spillage and theft (Birachi et al. 2011).

In the analysis, access to market information through traders was significant ($P < 0.01$), an indication that many farmers obtained market information in this way. However, the danger with this source of information is that the information

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[1] Bean is a staple food of several households in Central Africa.

cannot be as accurate as that obtained from other sources such as government, NGOs, and processing companies because the traders often want to get the lowest prices for beans purchased from farmers. Continuous lack of accurate, relevant, and reliable market information has been regarded as a major obstacle to improving agricultural development in sub-Saharan Africa. Very few farmers, particularly peasant farmers, have even limited access to information on the production and marketing of their produce. Farmers need better access to market information on prices, quality, quantities, where to sell, and production technologies which can be done through the establishment of market intelligence systems (MIS) by government and development partners in agricultural development. Poor market infrastructure in terms of transport and market information has weakened farmers' competitiveness in the market-oriented economy (Ferris and Robbins 2004).

The use of SMS in Burundi is not as advanced as in Kenya and Malawi. In Malawi, the SMS service is offered by the Malawi Agricultural Commodity Exchange (MACE) and in Kenya by the Kenya Agricultural Commodity Exchange (KACE). Commodity market information costs as little as US$0.10 for Malawi and US$0.046 for Kenya, compared with the transaction costs that would be incurred by the actors (including farmers) who would have to physically travel to a market to get information. Effective use of radio programs especially vernacular radio stations has proved useful in other countries since they increase the likelihood of the farmers purchasing seeds of the new improved varieties to increase production. These programs are normally sponsored by government, various donors, or NGOs to promote the production and marketing of a particular crop enterprise.

Bean networks play an important role with the potential to increase the level of commercialization of smallholders. Beans can be commercialized through the networks. However, there are very few networks in the region with more than 80 % of the farmers not knowing their existence and those who knew of the networks were able to sell more produce compared with those who did not know of their existence. Bean networks link farmers to organizations that promote production and to the market through export companies and potential buyers, fostering commercialization.

Conclusions and Recommendations

There are limited studies on bean utilization and commercialization in the Great Lakes Region with the majority in Eastern and Southern Africa compared to Central Africa. However, research in this area can enormously contribute to the formulation of market-oriented strategies by providing detailed information on output and providing market information that will motivate farmers to become commercial oriented. Production and marketing constraints reduce the output to a level that can be used only for domestic consumption with a limited marketable surplus. In addition, results indicate that farmers often rely on local seeds that have been characterized by low output. Therefore, with reference to Burundi, the following recommendations derived from the research are worth implementing:

1. Emphasis on interventions that increase farm-level productivity and market-led approaches to foster commercial linkages between potential buyers and rural communities will help to reduce poverty and address food insecurity in rural areas of Burundi. These may include linking farmers to input markets and developing market information systems (MIS) and rural extension – education programs.
2. Investment in advocacy for policy change in Burundi would facilitate the quick delivery of seeds of new seed varieties and link farmers to output markets. This should begin with the seed and output regulation and certification systems in the country which are currently very weak in addressing production and marketing challenges. Enacting effective regulatory measures will not only protect farmers from using poor quality seeds purchased from traders but also reduce farmers' transaction costs in looking for the best quality seeds for planting.
3. The national and regional bean programs such as Pan African Bean Alliance (PABRA) and other organizations working in the subsector should now address the processing and commercialization of beans among smallholder farmers since a lot has relatively been done on seed systems and production practices. These should include the promotion of industrial processing in Burundi just as in Kenya and Ethiopia, and the identification of market outlets that will ease the commercialization of beans and improve the food security status of farm households.

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Chapter 24

Improving the Availability of Quality Planting Materials Through Community-Based Seed and Seedling Systems: The Case of Rural Resource Centres in Cameroon

B. Takoutsing, A. Degrande, Z. Tchoundjeu, E. Asaah, and A. Tsobeng

Abstract Increasing the productivity in both crop and agroforestry subsectors is one of the measures taken to improve food security and livelihoods of subsistence farmers. This improvement can only be realized if subsistence farmers have access to quality planting material. The lack of high-quality planting material has been repeatedly identified as a major constraint to greater adoption of agroforestry innovations. The recognition of this fact has led to the development of national seed and seedling programs. However, the low capacity of these programs, the sluggish growth of the private sector, and the demand of subsistence farmers means they are obliged to seek alternative models. This paper discusses results and experiences drawn from a community-based seed and seedling production and dissemination system in the Western Highlands of Cameroon. The system is built on the concept of a rural resource centre in which capacities of farmers were strengthened to multiply improved planting material of four food crops and five fruit tree species. The rural resource centres are now sources of quality seeds and seedlings for farmers and institutional clients. The system has effectively improved the on-time dissemination, accessibility, affordability, and availability of quality planting material which are obtained at affordable prices due to proximity and reduced transport and distribution costs. Income from selling improved planting material has become an incentive for rural resources centres and helps to ensure sustainability of the system. Availability of quality seeds was found to increase on-farm crop yields by 20–40 %, while demand for improved seedlings has surpassed supplies in participating communities. The successful dissemination of this approach requires much more than the transfer of knowledge and availability of improved germplasm; it involves supporting the capacities of the rural resource centres, building partnerships with a range of stakeholders, increasing the involvement and interaction of government services, improving storage and marketing

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strategies, and decreasing dependency on external resources. The main challenge of the future is how to make such a system sustainable. Furthermore, in addition to the challenge of projecting and meeting the quantitative demands of farmers and other stakeholders, issues of seed quality and genetic diversity still need to be addressed when designing and implementing effective seed supply strategies and policies.

Keywords Community-based • Rural Resource Centre • Planting material • Quality seeds • Germplasm

Introduction

Increasing agricultural production is one of the measures taken to assure food security and livelihood enhancement in rural areas, but this improvement can only be effective and sustainable if subsistence farmers have access to affordable quality planting material (Mesfin 2005). The lack of this material has also been repeatedly identified as a major constraint to greater adoption of agroforestry innovations. Most small-scale farmers continue to rely largely on their own material, saved from previous seasons or obtained from neighbouring farmers (David and Sperling 1999; Rohrbach et al. 2002; Weber and Bonkoungou 1993; Weber et al. 1997). Improving the genetic and physical properties of planting material can trigger yield increases of up to 40 % and lead to substantial improvement in the agricultural production and food security, especially if farmers continue to renew their planting material (Maredia et al. 1999). In the Western Highlands of Cameroon, there are two sources of planting material: the formal and the informal systems. The formal system is dominantly supplied by research institutions and focused on cereals and crop seeds, while seedlings of different fruit trees and other perennial crops are produced in government and NGO-owned nursery sites. The informal system on the other hand includes material retained by farmers from the current harvest or obtained through farmer-to-farmer exchanges. Both systems have their own drawbacks. The capacity of the formal sector is too limited to supply the nation's demand, while the informal system is incapable of producing improved quality material. Tree planting material systems differ from crop planting material systems in that there are no bred varieties for most tree species and the attendant regulations exist only in developed countries; consequently, differences between formal and informal tree seed systems are largely blurred (Nyoka et al. 2011). It has been widely recognized that, more than any other input, improved planting material is the key to enhanced farm productivity and increased income generation (Hassan et al. 2001; Minot 2008; Takoutsing et al. 2013a). The recognition of this fact by the Government of Cameroon has led to the creation of programs in an attempt to enhance availability and wider participation of the private sector. Considerable advancements have been made and a range of regulations and policies have been adopted to protect farmers from the harmful effects of low quality material. However, the planting material situation in Cameroon remains dismal. Most of the programs do not recognize the vital role that small-scale farmers could play as producers and have focused on elite farmers with no obvious commercial linkages between the two groups.

An alternative is to strengthen the capacities of farmers and farmer organizations to produce and disseminate quality material for both crop and tree species (Buruchara and Kimani 2009; Weber et al. 2001). The advantages of farmer-based seed production over other approaches include sustainability, decentralization of seed production to cater for local supply, and opportunities for linking to formal institutions (David 2004). Well organized smallholder producers can achieve sustainable seed supply, increased market share and greater income (Catacutan et al. 2008). Several agricultural research organizations and NGOs have given their support for this type of approach. However, these emerging smallholder producers face a lot of problems in conducting their activities. Their difficulties range from access to basic equipment, technical and managerial skills, access to foundation material, limited agricultural land, lack of appropriate credit and other financial facilities necessary for developing their activities and insufficient support from the public sector and policy makers.

The World Agroforestry Centre (ICRAF), through the implementation of the Agricultural and Tree Products Program, developed a community-based and decentralized seed and seedling production and dissemination system to enhance the adoption and diffusion of quality planting material, improve their availability and accessibility, and have an impact on the livelihood of small-scale farmers. The approach strengthened the informal sector and linked it effectively to the existing formal sector. At the same time the program helped to build local capacity in the production and dissemination of quality material. The main purpose of this paper is to present the system, report its progress and achievements, and assess the potential of some of the farmers to successfully produce and market seed within their respective communities. The system is reviewed in relation to seed and seedling quality, availability, affordability, and delivery mechanisms. Major challenges of such systems are also presented as well as key elements that ensure sustainability.

Project Implementation Strategies

Brief Description of the Project

The Agricultural and Tree Products Program implemented by the World Agroforestry Centre and partners between 2007 and 2010 in the Western Highlands of Cameroon fell within the framework of the "Food for Progress Act" between the Governments of the Republic of Cameroon and the United States of America and was financed by the United States Department of Agriculture (USDA). Its main aim was to enhance household livelihood security through the improvement of

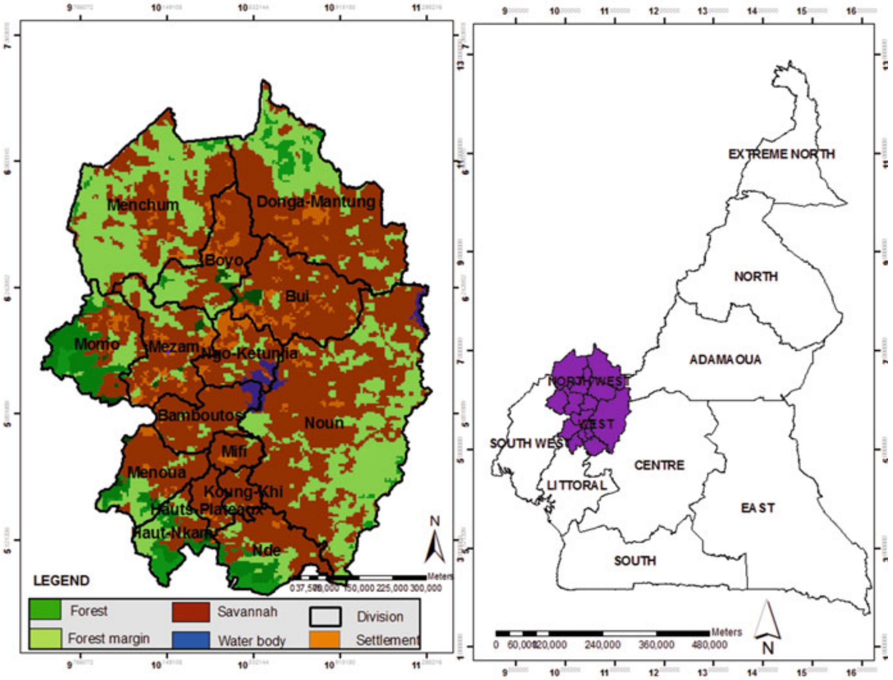

Fig. 24.1 Map of Cameroon showing the project site

agricultural and tree crop production, marketing and competitiveness in the project area. Specific objectives included securing household revenues by improving crops, tree products, and medicinal plant production; marketing and policy; promoting agribusiness or agricultural enterprises (especially in the tree products and medicinal plants subsector) and the creation of employment opportunities. The project achieved these by developing partnerships with a wide range of stakeholders including farmers, farmer organizations, private enterprises, civil society/NGOs and government services and agencies. The main hubs of interaction for various partners were the rural resource centres (RRCs).

Project Site

The project was implemented in the West and North West regions of Cameroon (Fig. 24.1), which make up what is referred to as the "Western Highlands" owing to their similarities in physical, human, economic, and cultural geographies. The Western Highlands lie between latitude 5°20′ and 7° North and longitude 9°40′ and 11°10′ East, with a surface area covering 17,910 km^2 (15 % of the country's land area). Altitude ranges from 300 to 3,000 m above sea level.

Mean annual rainfall varies between 1,300 and 3,000 mm. The minimum and maximum temperatures are 15.5° and 24.5 °C. The region is dominated by high volcanic mountains with fertile soils (hydromorphic, volcanic, and ferralitic) and has been traditionally the most densely populated part of the country (Takoutsing et al. 2013b).

The Concept of the Rural Resource Centre (RRC)

The main strategies for the implementation of the system were based on the concept of rural resource centres (RRCs) which were created in participating communities across the project area. These centres are community owned and managed with the support of the project. For the implementation of the seed and seedling systems, the RRCs were entry points for all the participating farmers through which foundation material and germplasm as well as various technical packages were channeled. At the same time, seed multiplication farms and tree nurseries were placed under the supervision of RRCs. This approach to agricultural extension focuses on building capacities to generate innovations throughout the agricultural production and marketing system. It lays emphasis on access to knowledge, interactive learning and networking—among farmers and between farmers and other stakeholders—that can help farmers improve their livelihoods. The RRCs are appropriate for promoting new technologies that are relatively "knowledge intensive" and often require farmers to acquire new skills. This was the case for various training and technical packages involved in the production and dissemination of improved planting material (Asaah et al. 2011; Tchoundjeu et al. 2010). In addition, the key services that the RRCs provide include information and demonstration of new technologies and innovations, access to market information, links with market actors particularly from the private sector, and a forum for the exchange of information among farmers and between farmers and other stakeholders.

Conceptual Framework of the System and Functional Mechanisms

The primary objective of the community-based and decentralized seed and seedling system is to increase crop productivity through the use of quality planting material, produced by small-scale farmers themselves in their own localities and on a sustainable basis. The project achieved this by helping to develop local capacities, motivating farmers to undertake planting material production as a means of generating income, training farmers groups in production practices, postharvest handling, quality control, and basic business methods; enhancing farmers' capacities to produce planting material in sufficient quantities according to local demands, and distributing this on time and at affordable prices. A number of stakeholders and

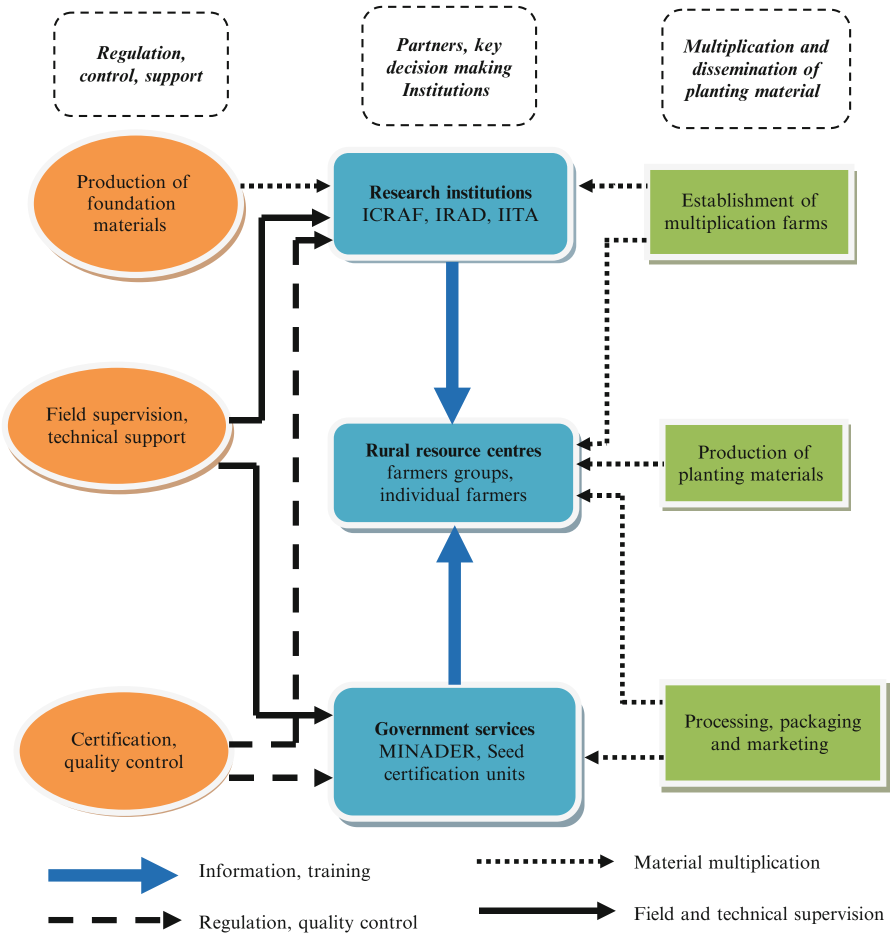

Fig. 24.2 Conceptual framework of the farmer-based seed and seedlings multiplication system

partners were involved including NGOs, research institutions, extension services, and government agencies.

The implementation of the system was carried out in various steps. First, the project coordinated a series of meetings to explain the project after which participating farmers and communities were selected. Then followed technical packages made up of various trainings and technical guidelines to facilitate the involvement of farmers. Through a participatory exercise, the main crops and priority tree species to be integrated in the system were selected; foundation material and improved germplasm of these species were procured and distributed to farmers for the establishment of seed multiplication farms and tree nurseries. Finally, linkages with other institutions facilitated the technical follow up, quality control, and certification. The conceptual framework of the system is presented in Fig. 24.2 showing the interactions between partners across various stages of material production and dissemination.

Table 24.1 List of crop and tree species integrated in the system

Main crops	Fruit trees
Maize *(Zea mays)*	Plum *(Dacryodes edulis)*
Potato *(Solanum tuberosum)*	Pea *(Persea americana)*
Plantain *(Musa acuminate)*	Kola (*Cola acuminata)*
Cassava *(Manihot esculanta)*	Mango (*Mangifera indica)*
	Bitter cola *(Garcinia kola)*

Group Strengthening and Institutional Capacity Building

The first step laid emphasis on a series of meetings to get the interest of the farmers to embark on seed and seedling production as a group activity and eventually as a lucrative business both at the household and community levels. This resulted in the selection of participating farmers and groups, and their organization into well-structured producer groups placed under the supervision of RRCs. The groups were then assisted to officially register with the local authorities and have legal status as common initiative groups (CIGs). Having a legal status empowers groups and facilitates access to local financial services for savings and access to loans. Social activities within groups were highly recommended to reinforce members' cohesion.

Selection of Main Crop and Priority Tree Species

Prior to the implementation of the seed and seedling system, a participatory exercise involving farmers took place to select the main crops and priority tree species to be integrated in the system. This resulted in the selection of four major food crops and five priority fruit tree species as shown in Table 24.1. The selection of these species reflected their importance in the area and their contribution to income and household food security.

Capacity Building in Seed and Seedling Production

To get the initiative underway and promote the role of local farmers in the system, the project organized series of technical training sessions to strengthen farmers' capacity and knowledge regarding various aspects of planting material production, processing, packaging, marketing, and distribution systems. Topics covered for crop seeds included selection of production sites, seed quality (genetic and physical purity, germination rate, weed and disease management), testing, postharvest handling, seed packaging, and certification. Training subjects for tree species multiplication included tree nursery establishment and management, germplasm collection and management, vegetative propagation techniques, on-farm tree management, and marketing. In addition, sessions on group dynamics were organized to ensure group cohesion, good governance and transparency, bookkeeping and management. Other partners, researchers, and specialists from local seed inspection services participated in various training sessions either as participants or as resource persons.

Support with Foundation Material and Improved Germplasm

After the training sessions, the project supplied 1,000 kg of potato seeds, 100 kg of maize seeds, 2,500 plantain suckers, and 20,000 cuttings of cassava and germplasm of the following fruit trees: *Dacryodes edulis, Persea americana, Cola acuminata, Mangifera indica, Garcinia kola* as seeds, cuttings, marcotts, and grafts obtained from research organizations to multipliers as foundation material. In addition, technical supervision that consisted of field visits, farms and nurseries evaluations, field discussions related to specific technical aspects, technical guidelines, and on-farm training were carried out at weekly (seed farms) and monthly (tree nurseries) intervals to ensure the proper use of the material and the application of norms and regulations that govern the production and distribution of planting material.

Establishment of Crop Seed Multiplication Farms and Tree Nurseries

The material supplied by the project coupled with technical backstopping resulted in the establishment of 42 seed multiplication farms (10 for potato seeds, 12 for cassava cuttings, 20 for maize seeds), 18 plantain plantlet multiplication units, stock plants and mother blocks, and 147 group nurseries involving about 2,550 farmers across the project area. Farmers used part of their farm land for seed production and their multiplication farms were regularly inspected by the staff of the seed certification unit of the Ministry of Agriculture and Rural Development (MINADER) to guarantee quality. Inspection fees that range between US$10 and 20 per visit were paid by the farmers but other field research activities related to production were shared between the project and other research institutions such as the International Institute for Tropical Agriculture (IITA) and the Institute of Agricultural Research for Development (IRAD) which were interested in knowing the on-farm performance of the material supplied and establishing sustainable linkages with the producers for future collaboration.

Linkages with Research Institutions, Government Services, and Extension Systems

Strong partnerships are essential to ensure both success and sustainability of any project related to the production and distribution of planting material (Rohrbach et al. 2002). The role and responsibility of each of the implementing partners need to be very clear to all. Government programs, research institutions, and especially NGOs have potential roles in promoting improvements in production, marketing, and distribution of planting material. Therefore, structural links through institutional arrangements were established between the project and other research institutions such as IRAD and IITA in order to sustain the supply of foundation material. These institutions also participated in the capacity building activities and took part in the technical supervision of multiplication farms to ensure that all the regulations and norms were respected.

Similar arrangements were established with government technical services such as the Ministry of Agriculture and Rural Development (MINADER) to ensure that producers were better supervised and technically assisted to produce quality material. Local seed certification units of MINADER in each locality were in charge of field supervision and certification. The quality of material produced was therefore controlled and certified. These units then became vital partners that ensured quality and prevented seeds of inferior quality entering the system.

Quality Control, Regulations and Certification

Material regulation in the system involved a range of activities from deciding which variety of crops or tree species to be multiplied, testing for purity in seed certification to regulating seed labeling and marketing. The quality control was an important part of the approach, as it was intended to ensure the physical and genetic quality of planting material supplied and to build farmers’ confidence in such material through certification tags. Material certification was the “official” seal declaring that the “certified” material had been produced from a proven, tested, improved and recognized genetic source, and that it had the stipulated germination percentage, purity, health and moisture content.

Material certification followed a kind of chain-control system, where the variety’s identity and purity were checked from the very first generation through a prescribed number of generations to arrive at sufficient quantities of final material that can be distributed to farmers. Standards for crops included, for instance, the distance to neighboring fields with the same crop or to weeds that may cross with the seed crop, the number of allowable off types; while standards for tree species included sources of germplasm, type of pots used, type of substrate used, and biological parameters such as sturdiness and the shoot to root ratio. Certification also involved strict procedures for labeling and packaging.

Data Collection

A monitoring and evaluation system was put in place from the inception of the project to collect all available data generated during the implementation of the project. Data collection forms were made available to each group. Data were collected on the quantity of planting material produced, type of fruit tree propagules, number of multiplication farms, distribution and marketing of material, number of participating farmers, and multiplication farms.

Project Achievements

Participating Farmers

The community-based and decentralized seed and seedling system concept was initiated, implemented, and accepted as part of the activities of the RRCs, and the project contributed in establishing several of such centres in participating communities. During the 4 years of its implementation (2007–2010), 12 RRCs were established or revitalized to support a total of 147 farming groups with a membership estimated at 2,550 farmers with 40 % being women (Table 24.2). It is noteworthy that, contrary to most smallholder projects where the lifetime of the groups is usually equal to that of the project duration, 80 % of the RRCs consolidated their activities and are still continuing to produce planting material after the end of the project.

Strengthening Capacities of Farmers and Other Stakeholders

A total of 64 crop germplasm multipliers received practical training on seed production, harvesting and postharvest operations, conditioning, storage, and marketing of crop material. Meanwhile, 120 tree nursery operators and staff of relay organizations and government services received training on germplasm collection, tree nursery establishment and management, vegetative propagation techniques, tree integration, and marketing of seedlings and tree products. Farmers showed willingness to produce improved material and followed the necessary multiplication regulations and standards.

Production and Dissemination of Improved Planting Material

In 2010, total seed produced was estimated at 22 tons (t) for maize, 20 t for potato, 18,000 plantain suckers, and 40,000 cassava cuttings For the five tree species integrated in the system, a total of 186,646 improved seedlings were produced in various types of propagules; 35,900 marcotts, 11,100 cuttings, 46,323 grafted plants, and 93,323 seedlings (Fig. 24.3). Material dissemination was coordinated through linkages with relevant government institutions such as MINADER

Table 24.2 Evolution of the number of Rural Resource Centres (RRCs) and affiliated groups during the project lifespan (2007–2010)

	Years			
	2007	2008	2009	2010
Number of RRC	4	8	14	12
Number of Affiliated groups	47	126	150	147
Number of Farmers involved	215	1,500	2,612	2,550

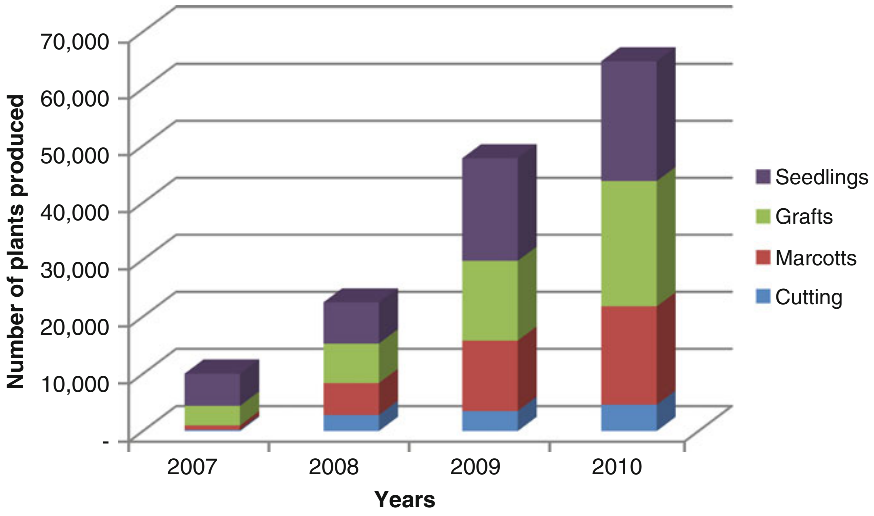

Fig. 24.3 Production of improved plants by groups

and other development organizations. Part of the planting material produced by smallholder farmers (60 %) were sold to generate income, while 25 % were used to establish new multiplication farms, and 15 % was distributed free-of-charge to various group members to boost crop and tree production. MINADER through its numerous agricultural projects also promoted the commercialization by creating links between producers and users.

Contribution to Food Security and Poverty Alleviation

Participating farmers stressed that the business was profitable and had helped to diversify their activities, increase their income and achieve a higher standard of living. Total income generated from the sales of planting material in 2010 was estimated at about US$65,000 for improved seedlings and US$17,000 for crop seeds. The income generated by RRCs and farming groups has become an incentive for promoting the community-based system. If the current prices are maintained or increased, it is expected that more farmers will engage in production of planting material production.

Effects on Food Production and Productivity

The use of quality planting material by farmers already led to increased yields in demonstration farms owned by participating farmers across the project area. For the

Table 24.3 Average yield increase as a result of using improved seeds of major crops

Crops	Yield obtained in 2007 (t/ha)	Yield obtained in 2010 (t/ha)	Yield change (%)
Maize *(Zea mays)*	1.2	1.8	35
Potato *(Solanum tuberosum)*	6.6	11.0	40
Plantain *(Musa acuminata)*	10.1	12.8	21
Cassava *(Manihot esculanta)*	7.8	10.6	26

case of maize, farmers normally obtain 0.5–1.1 t/ha with farmer-saved seed, but with the use of improved seed and good farming practices, up to 1.8–2 t/ha were obtained in 12 demonstration farms (Table 24.3). The same tendency was observed with potato on six demonstration farms, plantain on five demonstration farms, and cassava on eight demonstration farms with an increase in yield ranging between 20 and 40 %. This is a tremendous productivity gain in the area and calls for an increased investment in the use of good quality planting material.

Yields on the same plots prior to the implementation of the project were lower than the present figures (Table 24.3). In addition to the use of improved planting material, the project also encouraged the farmers to used sustainable agricultural and agroforestry practices such the use of manure. This could have also enhanced land productivity and consequently contributed to the yield increase on demonstration plots.

Sustainability of the System and Lessons Learnt

Despite the above-mentioned achievements, sustainability of RRCs is a major concern. To help sustain the community-based and decentralized seed and seedling system put in place by the Agricultural and Tree Crop Programme in the Western highlands of Cameroon, the required technical skills need to be present at individual, community, and national levels because producing improved planting material requires a range of technical capacities. Continued improvement of farmers' skills and knowledge at various stages of production could enhance uptake, improve practices, and keep the system commercially viable. Reinforcing the interaction between farmers, research institutions, and government technical services coupled with financial and technical support from extension services is essential during the early stages of development of the system. The duration of project activities, particularly those related to agroforestry practices, has sometimes hindered sustainability of certain initiatives. This was the case for the Agricultural and Tree Crop Programme that lasted just 4 years. The same tendency is reported by Nyoka et al. (2011) in Malawi where most funded agroforestry programs are less than 5 years, which may be too short to really establish and operationalize tree planting material systems. He also suggested the need for government and development partners to develop and implement seed supply systems as separate entities rather than bunch them together with other programs that may have short implementation periods.

Challenges and Opportunities

The project has of course faced several challenges—a number of which still have to be overcome. First, there is a perception amongst potential local buyers that the quality of material that is being produced by the project multipliers is not of the same high grade as that available from the research institutions. Local farmers sometimes judge the material by its appearance, regard it as inferior to that supplied by research institutions, and are therefore unwilling to pay the prices asked by the producers. Consequently, producers have been sometimes obliged to accept lower prices and will have to continue to do so until they improve their packaging and marketing strategies. This situation has also been reported in Malawi where most small-scale farmers are unwilling to pay premium prices to their neighbors for seed obtained from their own harvests (Rohrbach et al. 2002).

There have also been challenges with the marketing of surplus material outside the immediate locality. Again it is a question of confidence in the material—this will be difficult to overcome until the quality of presentation of the material has been improved.

To increase the sales of planting material produced by farmers, promotion activities should be conducted to raise awareness of all farmers in communities under smallholder seed production programs (Kibiby et al. 2001). Activities are currently underway to strengthen links between the producers, the agricultural research institutions and MINADER to tackle the problem of material presentation. Finally, multipliers need technical back-up to ensure long-term sustainability of their activities.

Conclusion

This experience in the Western Highlands of Cameroon has shown that it is possible to fill the gaps left by government and the private sectors in the supply of improved planting material. Supporting the establishment and development of community-based and decentralized systems remains a vital alternative. The success of the model described in this paper is attributed to the good partnership with public and private institutions. However there is need for policy reforms for strengthening, streamlining, and developing the sector as suggested by Kugbei and Bishaw (2002) and Mulatu et al. (2005). In addition, a lot needs to be done in the area of tree planting material. There have been a lot of improvements in terms of physical quality but not much progress has been made as far as genetic quality is concerned. There is need to continually reinforce the technical know-how of farmers on issues of quality tree planting material (Nyoka et al. 2011). The model has not only produced tons of quality seeds and thousands of improved seedlings that are important for national food security but it has also contributed to an improvement of the livelihoods of farmers. However, the agricultural extension system has to continue to educate farmers on the importance of the material in order to increase demand. The government should continue to support the input sector and ensure that capacity building, particularly in production and marketing, is assured. The Western Highlands model is a success story that can be adapted to similar conditions in other countries where the production of planting material is only just beginning.

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Chapter 25
Returns to Production of Common Bean, Soybean, and Groundnut in Rwanda

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Abstract Common bean and soybean are among the key crops for which specific actions are planned in the Plan for Agricultural Transformation in Rwanda (SPAT). Legume-based systems provide high-quality food, cash to farmers, and contribute to sustainable agricultural production systems. The aim of this study was to evaluate and compare the profitability of common bean, soybean, and groundnut cropping systems and examine the change in soybean profitability in response to variation in market price and yield. Data was collected through focus group discussions (FGDs), interviews with key informants, and formal questionnaire survey. The data were organized and analyzed using the enterprise gross margins approach. Results showed that soybean sole cropping systems were associated with low to high profitability both in terms of returns to land and returns to labor, low returns being predominant. The sensitivity analysis results led to two important conclusions. First, the increase in producer price will mostly benefit farmers who can achieve higher yields while having limited impact on the profitability of those lagging behind in soybean yield. Second, a price increase, although essential in the process of boosting soybean profitability, is not the best solution in the presence of low yield levels, if the necessary conditions are not present to permit a subsequent increase in yields. Common bean cropping systems were also characterized by low to high returns to land and labor with moderate returns being more frequent.

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Although climbing bean cropping systems had higher yields compared to bush beans, the two types of common bean had comparable returns to land due to high extra costs on labor and stakes associated with climbing bean.

Keywords Common bean • Soybean • Groundnut • Returns to land • Returns to labor • Rwanda

Introduction

In the 1970s and 1980s the overriding concerns of the Government of Rwanda (GoR) for agricultural production, marketing, and trade policy in food crops was to protect local producers from food shortage. This concern was based on the desire of a high degree of food self-sufficiency in the country. On realizing that food self-sufficiency was not being fully achieved, the GoR considered switching to a market-oriented food policy based on national self-reliance in the early 1990s. The Government felt that this would lead to food security, economic growth, and overall development. The current Strategic Plan for Agricultural Transformation in Rwanda (SPAT) is based on “voluntaristic stimulation and incentives for the production systems towards regional specialization, producer’s professionalism, commodity chains and the market-orientation” (Republic of Rwanda 2004). Common bean and soybean are among the key crops for which specific actions are planned in SPAT. On the other hand, the promotion of groundnut is considered in the context of diversifying oil crops in the country. According to Kelly and Murekezi (2000), a strong program of fertilizer promotion for climbing bean and soybean (in combination with inoculation) will result in profitable outcomes for farmers in some agroecological zones in Rwanda. Legume-based systems provide high-quality food and cash to farmers as well as contributing to sustainable agricultural production systems.

Faced with multiple agricultural enterprises, farmers need information on which of the enterprises is most profitable. Such information can be availed after conducting an enterprise gross margins analysis. This analytical approach is based on the concept of separability and comparability of different farm enterprises. With this concept, individual farm enterprises are assumed to be largely separable and identifiable more or less in isolation so that measures can be made of their technological and economic efficiency on an individual enterprise basis, comparisons made among them, and recommendations made that some enterprises should be expanded and others contracted (Dillon and Hardaker 1989). This is in line with the current GoR’s crop intensification and land use consolidation programs that aim at improving the productivity of crops and increasing improved input availability. The core activities in implementing these programs consist of consolidating farmers’ plots for growing specific crops (grown in pure stands) and bulk buying of improved inputs (mineral fertilizers and seeds).

The aim of this study was therefore to evaluate and compare the profitability of common bean, soybean, and groundnut cropping systems and examine the change in soybean profitability in response to variation in market price and yield. More specifically, the study was undertaken to provide information that will assist farmers in decision making on these grain–legume cropping systems given their returns to land and labor and also provide government with information concerning farmers and their management practices, so as to support policy formulation and development planning.

Methodology

The Enterprise Gross Margin Budget Approach

In general, an economic agent makes private investment decisions on the basis of past, present, and expected future market prices for inputs and outputs. It is then accepted that the incentive a farmer has to produce a commodity will depend on the price he receives for his product and the cost of inputs used in the production of the commodity (Gittinger 1984; Tan et al. 2001; Campbell and Brown 2003). In other words, a farmer can only continue to operate if he receives reasonable returns to his investments and efforts. This is measured by the profit the farmer expects from the activity. The higher the past or expected profit of an activity is, the more willing the farmer will be to shift resources toward that activity. The profitability of an activity is measured using current market prices and represents the difference between the value of output and the value of inputs used to produce the commodity (Schaefer-Kehnert 1980 cited in Gittinger 1984). It is obtained through the formulation of either an enterprise budget or an enterprise gross margin budget. The latter is a partial profit budget drawn up using enterprise gross margin that can be defined as the gross income from an enterprise less the variable costs incurred in achieving it. Variable costs are those directly attributable to an enterprise and which vary in proportion to the size of an enterprise. This approach was used in this study to evaluate returns from common bean, soybean, and groundnut production. Returns from the production of the crops were calculated as follows:

$$\begin{aligned} \mathit{Total\ returns\ to\ land} = {} & \mathit{Value\ of\ output} \\ & - (\mathit{Labour\ cost} + \mathit{Intermediate\ inputs}) \end{aligned}$$

$$\begin{aligned} \mathit{Total\ returns\ to\ labour} = {} & \mathit{Value\ of\ output} \\ & - (\mathit{Value\ of\ land\ used} + \mathit{Intermediate\ inputs}) \end{aligned}$$

The identification of the various tasks in crop production constitutes the first step in crop-specific budget preparation (Monke and Pearson 1989). The next step involves the specification of inputs and outputs associated with each task of the cropping calendar. While outputs are placed in a single category; inputs are classified into fixed, direct labor, and intermediate inputs. Fixed inputs are not considered since it is the gross margin that is to be computed. Direct labor inputs include both family and hired workers.

The collected data are used to compute returns to land and labor. One way of analyzing returns to a given resource is to deduct from the total gross margin the costs of all resources except the one we are particularly interested in. The value of labor per person-day is then obtained by dividing total returns to labor (value of production minus cost of inputs other than labor) by the total number of person-days. The estimated figures are to be compared with the daily wage rate. On the other hand, since the total gross income and input costs are evaluated on a per hectare basis, the value of land per hectare is obtained by deducting from the total gross margin the costs of all resources except the monetary value of land used.

Estimation of Production Parameters

Output prices were average local market prices during the 2 months following common bean, soybean, and groundnut harvesting. The costs of all farming activities (clearing, plowing, planting, weeding, harvesting) were computed from the household survey data on the cost of hired labor. Land cost was computed on the basis of crop plot area and the average land rent per season in the region during the fieldwork. The cost of intermediate inputs, that is, seeds, fertilizers, and crop protection products was determined from their local market price.

Sensitivity Analysis

Sensitivity analysis is an analytical technique that consists of altering factors such as output price, input cost, and crop yield either one at a time or a combination of these from their baseline factors to include a range of potential values (Gittinger 1984; Lu et al. 2003). In this study the sensitivity analysis incorporates soybean yield increase varying from 0.6 to 1.6 t/ha while the producer price varies from Rwanda Francs 150 to 350/kg of soybean grains at 50-Franc intervals but depending on prevailing price in the region in 2007. The calculations of profitability at various yield levels are made assuming that yield increases to 0.8 t/ha and above are achieved through the use of 80 kg of DAP plus 10 kg of Urea as recommended.

Data Collection

Primary common bean and groundnut data were collected in Umutara, Kibungo, and Bugesera regions covered by the CIALCA-TSBF project. Soybean data were collected in Bugesera, Gitarama, and Gikongoro, three of the major soybean producing regions in Rwanda. The survey covered three villages (cells) per crop per site. In each village 10 farmers were randomly selected among those who were available when the survey team arrived. A total of 30 farmers were interviewed for each of the three crops per site.

Data were collected through focus group discussions (FGDs), interview with key informants, and formal questionnaire survey. Three FGDs were organized in three districts (Bugesera, Kirehe, and Gatsibo). Each FGD included representatives of farmers growing common bean, soybean, and groundnut, representatives of traders and local extension agents, and covered production systems and grain marketing. Interviews with key informants were carried out in two districts (Kamonyi and Huye) on soybean production and marketing in particular.

The data collection was based on one agricultural season and covered major crops grown in the region; quantity produced, sold, and stored; quantity of inputs used; common bean, soybean, and groundnut plot area; and other pertinent variables.

Returns to soybean, common bean, and groundnut production were expressed in terms of private profitability at the farm level. They were evaluated and discussed first on a per-hectare basis (returns to land) and then on a per-person-day basis (returns to labor). The estimation of private profitability was based on grain yields and production costs prevailing in 2007. Results are presented per region.

Results and Discussion

The selection of cropping systems based on their importance in terms of the magnitude of seasonal output ended up with five major soybean cropping systems, five major common bean cropping systems, and three major groundnut cropping systems. In Gikongoro, four soybean cropping systems are more common among soybean growers, made up of two mixed cropping and two sole cropping systems; three of these include the use of organic fertilizers. Gitarama has also four more common soybean cropping systems, having in common with Gikongoro three of these. Kibungo has apparently less soybean cropping systems and most of them do not include the use of organic fertilizers. Results showed that soybean growers in all the three regions are not familiar with the use of mineral fertilizers.

The two types of common bean, that is, bush bean and climbing bean were grown in Bugesera and Kibungo while in Umutara bush bean was by far predominant. In Bugesera, four common bean cropping systems were more common among farmers, bush bean being more represented either in sole cropping or mixed cropping. On the other hand, bush bean and climbing bean seemed to be equally distributed among the common bean cropping systems in Kibungo. Most of the common bean cropping systems in the three regions were found on upland plots.

Groundnut was produced in fewer cropping systems compared to soybean and common bean. Three cropping systems were more common in the three regions covered by this study. In Kibungo and Umutara, groundnut was mostly grown in sole cropping and mixed cropping on upland plots while in Bugesera, more

Table 25.1 Estimated yields of soybean, common bean, and groundnut cropping systems

Cropping systems	Gikongoro (kg ha^{-1})	Gitarama (kg ha^{-1})	Kibungo (kg ha^{-1})	Bugesera (kg ha^{-1})	Umutara (kg ha^{-1})
Pure stand of soybean on upland plot with organic fertilizer	758 (146)	749 (175)	1,148 (167)	–	–
Pure stand of soybean on wetland with organic fertilizer	996 (180)	1,137 (207)	–	–	–
Pure-stand of soybean on upland plot without organic fertilizer	–	–	815 (166)	–	–
Pure-stand of bush bean on upland plot	–	–	962 (288)	619 (160)	1,045 (194)
Pure-stand of bush bean on wetland plot	_	_	_	903 (207)	_
Pure-stand of climbing bean on upland plot	_	_	1,517 (193)	1,393 (346)	_
Pure-stand of groundnut on upland plot	_	_	792 (116)	611 (103)	637 (71)

common groundnut cropping systems were pure stands either on upland plots or in marshlands. Given the objective of the study which was to compare the profitability of cropping systems in terms of returns to land and labor and, following the concept of separability and comparability of different crop enterprises, mixed cropping systems were not considered in subsequent discussions.

Returns to Land

Returns to land associated with soybean, common bean, and groundnut production at the farm level are summarized in Tables 25.1 and 25.2.

Soybean yields were relatively low to moderate, cropping system averages ranging from 749 to 1,148 kg/ha (Table 25.1). Soybean yields were lower (749–815 kg/ha) for cropping systems without organic fertilizers compared to kg/ha the cropping systems with organic fertilizers (758–1,148 kg/ha). Wetland plots gave on average higher soybean yields than upland plots, suggesting that the crop suffered a deficiency in moisture and soil nutrients on upland plots in Gikongoro and Gitarama. Comparison between regions revealed that soybean performed better in Kibungo from cropping systems without organic fertilizers. Kibungo is indeed known to have better soils, compared to the other two regions, its major problem being irregular rainfall.

Compared to soybean, common bean appears to have better yields which are however lower than the yields that would be achieved with improved varieties and better crop management. Climbing bean cropping systems recorded higher yields than bush beans (Table 25.1). The question is whether the difference in yields

Table 25.2 Returns to land for major soybean, common bean, and groundnut cropping systems

Cropping systems	Gikongoro (Frw ha^{-1})	Gitarama (Frw ha^{-1})	Kibungo (Frw ha^{-1})	Bugesera (Frw ha^{-1})	Umutara (Frw ha^{-1})
Pure stand of soybean on upland plot with organic fertilizer	38,583 (4,544)	40,447 (7,346)	79,755 (11,589)	–	–
Pure stand of soybean on wetland with organic fertilizer	9,574 (1,811)	38,451 (8,966)	–	–	–
Pure-stand of soybean on upland plot without organic fertilizer	–		33,108 (6,759)	–	–
Pure-stand of bush bean on upland plot	–	–	69,573 (20,851)	14,586 (3,765)	59,629 (11,090)
Pure-stand of bush bean on wetland plot	–	–	–	49,808 (11,375)	
Pure-stand of climbing bean on upland plot	_	_	57,033 (7,272)	51,629 (12,816)	_
Pure-stand of groundnut on upland plot	_	_	66,334 (9,679)	75,008 (13,651)	49,353 (5,510)

is high enough to justify the extra effort in terms of labor (staking) and costs associated with acquiring stakes, needed to grow climbing bean,

Results in Table 25.1 show that the common bean performs better in Kibungo and Umutara compared to Bugesera (bush bean in particular). Umutara is known to be the highest common bean supplier to Kigali market. However, yields were low compared to a potential of about 2.5 t/ha for bush bean varieties and 5 t/ha for climbing varieties (AGRA 2009).

Results in Table 25.1 revealed that groundnut had lower land productivity when compared to common bean and soybean. Furthermore, yields were in general not better than the 2002 national average of about 610 kg/ha (ICRISAT 2009).

Investigation of the relationship between yield and profitability revealed that technology (e.g., crop variety, Rhizobium inoculation, cultural practices) improved profitability (Chavas et al. 2001; Lu et al. 2003; Ouédraogo 2003; Ndakidemi et al. 2006). Results of our analyses on soybean agree with their findings. In fact, returns to land from soybean grown with organic fertilizer is more than twice returns to land from soybean grown without organic fertilizer in Gikongoro (Table 25.2).

Only one out of three soybean sole cropping systems generated returns to land greater than FRW 50,000 (US$100) Rwanda Francs per hectare, the average land rent per season during the fieldwork (Table 25.2). Soybean grown in pure stands on upland plots with organic fertilizer had on average better returns to land. On the other hand, pure soybean stands on wetland plots had, on average, lower returns despite higher soybean yields due to high labor costs associated with wetland soil

Table 25.3 Returns to labor in Rwanda (in Rwanda francs per person-day)

Cropping systems	Gikongoro	Gitarama	Kibungo	Bugesera	Umutara
Pure stand of soybean on upland plot with organic fertilizer	358 (42)	373 (87)	510 (74)	–	–
Pure stand of soybean on wetland with organic fertilizer	300 (57)	371 (67)	–	–	–
Pure stand of soybean on upland plot without organic fertilizer	–	–	335 (69)	–	–
Pure stand of bush bean on upland plot	–	–	504 (151)	226 (58)	434 (81)
Pure stand of bush bean on wetland plot	–	–	–	399 (91)	–
Pure stand of climbing bean on upland plot	–	–	432 (55)	406 (101)	–
Pure stand of groundnut on upland plot	–	–	433 (63)	494 (90)	398 (44)

Source: Authors
Figures in *parenthesis* are standard deviations

preparation. This result suggests that soybean production was associated with low to fair returns to land in the three sites.

Results on returns to land from common bean showed that bush bean was superior to climbing bean in Kibungo while in Bugesera climbing bean had high returns. In fact, the extra yields of climbing bean compared to bush bean generated enough revenue to offset the extra costs on labor and stakes in Bugesera but not in Kibungo. These results agree with Purvis et al. (1995) who observed that for some technologies extra costs are not always offset by net returns.

Compared to the other two grain legumes, common bean had slightly better returns to land than soybean but was comparable with groundnut. The latter have good returns to land mostly due to better groundnut local market prices. As mentioned earlier on, groundnut had lower yields compared to those achieved by common bean and soybean.

Returns to Labor

Besides the return to land (net benefit per hectare) estimated in the previous section, another measure worth noting is the value of labor used in common bean, soybean, and groundnut production. The estimation of the value of labor per person-day provides an indication of how many units of labor are being remunerated when devoted to common bean, soybean, and groundnut production. Results in Table 25.3 show that in 2007, soybean growers in all the four regions (except Kibungo) earned lower returns per person-day but not very far from the daily wage rate (which was Rwanda francs 400 during the period data were collected). Although soybean growers in Kibungo got the highest returns to labor, common bean production appeared to remunerate better labor than soybean production. In fact, the average returns to labor from common bean were almost equal or higher than the daily wage rate except for pure stands of bush bean on upland plots in Bugesera. Groundnut growers were fairly remunerated throughout the regions covered by this study. In Bugesera they had better returns to labor compared to soybean and common bean growers.

Potential Impact of Changes in Yields and Producer Price

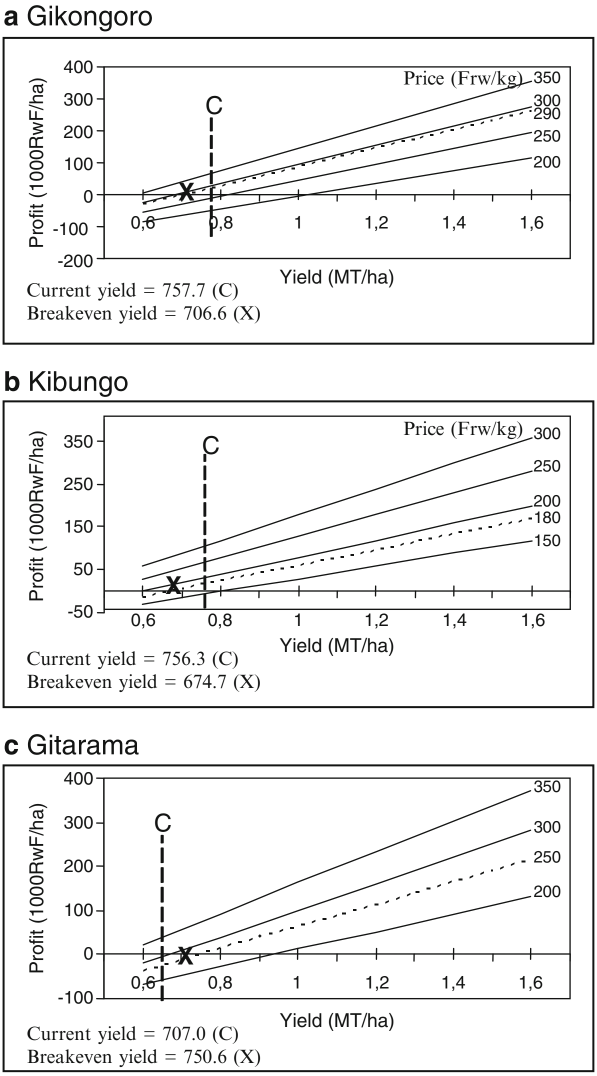
Results of private profitability are affected by grain yields, producer price, and prices at different levels of market channels. Higher yields result in higher profits for producers all factors being equal. Yields at farm level determine total production and thus quantities purchased by traders. Grain yields at the farm level have then an indirect effect on private profitability at the post-farm level since fixed costs are spread over larger quantities lowering unit costs due to economies of scale. It is indeed known that unit costs of transportation are relatively low where regional specialization has been developed. Furthermore, the profit (per unit weight) can be tiny and still be quite adequate when the volume involves thousands of kilograms per transaction. The purpose of this section is to assess how sensitive soybean profitability is to soybean yield and producer price change (a decrease or an increase) following Gittinger’s technique of sensitivity analysis in the framework of “most probable outcome analysis” (Gittinger 1984).

Figure 25.1 shows the effect of changing yields and producer price on soybean grower profit in the three regions of the study.

We can first consider the impact of changing yields while keeping the producer price constant at the current level (dotted line). At the prevailing producer price and 2007 soybean yields, soybean growers in Gikongoro and Kibungo can achieve slight positive profits while Gitarama soybean producers earned negative returns. As yields are increased from the current low levels to potential high levels, returns to land increase significantly in all the three regions but in particular in Gikongoro and Gitarama where current prices are higher. Under current price conditions, soybean yields must be at least 675 kg/ha for soybean growing activities to generate positive profits, as shown by breakeven yield figures.

The producer price has considerable impact on the profitability of soybean production as one can see from the increase in the slope of profit lines as the price increases. It is obvious that a simultaneous increase in price and yield results in even higher net benefit, as shown by the vertical distance between profit lines at a given yield in each of the three regions. In fact, the higher the yield, the higher the impact of a price change.

Fig. 25.1 Impact of changing soybean yields and prices at the farm level (Source: Computed by authors)



Conclusion

The objective of this study was to evaluate and compare the profitability of common bean, soybean, and groundnut cropping systems and examine the change in soybean profitability in response to variation in market price and yield. Soybean sole cropping systems are associated with low to high profitability both in terms of returns to land and returns to labor, low returns being predominant. A careful analysis of sensitivity analysis results leads to two important conclusions. First, the increase in producer price will mostly benefit farmers who can achieve higher yields while having limited impact on the profitability of those lagging behind in soybean yield. Second, a price increase, although essential in the process of boosting soybean profitability, is not the best solution in the presence of low yield levels, if the necessary conditions are not present to permit a subsequent increase in yields.

Common bean cropping systems were characterized by low to high returns to land and labor with moderate returns being more frequent. Although climbing bean cropping systems had higher yields compared to bush beans, the two types of common bean had comparable returns to land due to high extra costs on labor and stakes associated with climbing beans.

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Chapter 26
Institutions and the Adoption of Technologies: Bench Terraces in Rwanda

Alfred R. Bizoza

Abstract Local institutions shape the adoption of soil and water conservation (SWC) technologies. Various techniques for SWC are used once adopted by farmers such as bench terraces and hedges. Some farmers are reluctant for the adoption to a number of factors including institutions in their diverse forms. The paper specifies ‘soft’ and ‘hard’ social capitals, among other factors, to estimate their impacts on adoption of bench and progressive terraces in rural Rwanda- dominant forms of SWC in the history of land conservation in Rwanda. Data used for this study were collected among 301 households who also provided information on 907 plots located in the Northern and Southern Provinces in Rwanda. Sample households were selected using a stratified random sampling procedure. The results substantiate that some forms of social capital, i.e. trust and co-operation in collective labour, matter in the adoption process of bench terraces in Rwanda. These findings postulate that soil and water conservation is driven by local institutions. Unlike earlier work on the adoption of SWC measures, tenure security does not explain the adoption of bench and progressive terraces in rural Rwanda. Findings show also that bench terraces were constructed on plots with either gentle or steeper slopes. Farmers need more training before they embark upon the terracing process to ensure technical efficiency and sustainability of established terraces. Finally, the above findings confirm the hypothesis that local institutions play an important role in the adoption of bench terraces in rural Rwanda. Therefore, the results of this study help to guide both research into and policy on how local institutions can play better roles and the extent to which the institutions can substitute direct interventions by NGOs and policy-makers in soil and water conservation in Rwanda.

Keywords Institutions • Social capital • Bench terraces • Rwanda • Soil and water conservation (SWC)

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Introduction

The alarm of soil erosion and declining soil fertility in Africa is still buzzing. Who is going to switch it off? How and when? These remain important policy and research questions about land degradation and conservation in Sub-Saharan Africa. Soil and water conservation has been an integral part of agricultural development in Africa since the early twentieth century. Successive governments and development organizations invested heavily in different measures to reduce erosion and to promote sustainable agriculture since colonial Africa. However, soil erosion problems persist. Bench or stone terracing is one of the soil and water conservation (SWC) techniques promoted in East Africa (e.g. Ethiopia, Kenya, Tanzania, Rwanda) since the 1960s. Its adoption and continued use by small-scale farmers has been criticized invariably by scientists (Tenge et al. 2004; Pretty and Shah 1997; Shiferaw and Holden 1998).

Previous studies identify factors that drive adoption of agricultural technologies. These vary from bio-physical, socioeconomic, and institutional factors (Feder et al. 1985; Knowler and Bradshaw 2007; Rezvanfar et al. 2009; Graaff et al. 2008). However, the analysis of what drives or impedes agricultural technology adoption focused more on geographical conditions, people's economic and demographic characteristics, less on the role of local institutions (Knowler and Bradshaw 2007). The current trend in the literature recognizes the specific role of local institutions in land conservation and in natural resource management more generally (e.g. Sanginga et al. 2010; Bouma and Bulte 2008; Isham 2002).

Despite theoretical claims that social capital matters for investments in SWC measures, few empirical case-studies exist for Eastern Africa (e.g. Nyangena 2008; Isham 2002). Moreover, Graaff et al. (2008) present a summary of factors affecting adoption and continued use of SWC measures (including terraces) from recent studies in five developing countries: Tanzania, Ethiopia, Peru, Bolivia, and Mali. Institutional variables considered include land tenure, extension contracts, programme participation, and group participation. These factors measure 'structural' social capital. Trust, as part of 'cognitive' social capital, is not considered. To the author's knowledge, no study has related empirically these forms of social capital to the adoption of SWC measures in Rwanda. This paper investigates their impact on the adoption of bench and progressive terraces in the North and Southern provinces of Rwanda.

The main objective of this paper is to analyse the impact of various (local) institutions on the adoption of bench terraces in Northern and Southern Rwanda. The paper responds to one question in particular: are institutional or geographical variables more relevant to explaining the adoption of terraces? This study fits into the wider literature (mainly cross-country) on institutions versus geography/endowments as determinants of development.

Soil and Water Conservation and Institutions in Rwanda

Institutions and Soil and Water Conservation

Relevant institutions are empowered to ensure the long-term sustainability of established SWC measures by both governmental and non-government organizations (NGOs). One of the controversies centres on the issue that previous attempts in soil and water conservation by these organizations were top-down with only partial success in many developing countries, including Rwanda (e.g. Graaff 1996).

The results contribute also to the increasing scientific debate on the substitutability or complementarity of local versus formal institutions (e.g. Ahlerup et al. 2009; Bigsten et al. 2004). It appears in the Rwandan context that both government (formal) and local people (informal) based institutions are functional in rural development. Soil and water conservation serves for a fertile ground where both types of institutions coexist. The measure of the impact of local institutions presented in this paper is based on investments in bench terraces of which both public and private benefits evolve.

Land tenure security and social capital are both institutions are part of institutions (hard and soft) that affect the investment in soil and water conservation in many parts of Africa and Rwanda (Tenge et al. 2004; Shiferaw and Holden 1998). There is a lengthy academic debate on tenure security and land investments in Africa. Deininger and Feder (2009) summarize some of the discussion: tenure security lowers spending to protect (land) rights, increases levels of investments (as the future fruits of current investments are likely to appeal to investors) and, possibly, empowers women. However, these effects are less certain in situations of better functioning land markets (including rental rights) and improved access to credit (due to collateral).

Many African states have attempted to ensure long-term land rights through formalization (Barrows and Roth 1990). The formalization of land rights is not a panacea. Sometimes it is not necessary as customary land-right systems are functioning well (André and Platteau 1998), and due to the considerable costs associated with a full-fledged titling scheme (e.g. definition, measurement, and enforcement). A study by Saint-Macary et al. (2010) in Vietnam also concludes that ‘the issuance of land titles is a necessary but not a sufficient prerequisite to encouraging the adoption of soil conservation practices’. This brings us to the distribution of socio-economic power, governance and the nature of interventions (Deininger and Feder 2009). In relation to governance issues, one needs to know whether there is impartial access to the judicial system in order to guarantee land rights. If not, land rights may only exist on paper. Hence, we should look beyond tenure rights to understand investments in land quality.

Turning to the local level, do other dimensions of the institutional framework matter? The literature suggests that social capital is relevant. Social capital translates into reduced transaction costs (precluding the necessity to write contracts that capture all contingencies), facilitates the exchange of information, and enhances trust

(Krishna 2004). In addition, social capital enables communities to overcome social dilemmas, which is particularly relevant in the context of sizeable investments such as the construction of bench terraces to counter erosion (Isham 2002; Nyangena 2008). Bouma et al. (2008) show that social capital based on trust and co-operation enabled community resource management in India. On the other hand, social capital does allow for different interpretations due to the variability of cultures that endorse different mechanisms and expressions of social capital (Krishna 2004).

Social capital is important in Rwandan rural society. This paper distinguishes between different types of social capital. It examines cognitive (or soft) social capital and structural (or hard) social capital, and their effects on technology adoption. There is a growing body of literature that associates social capital with improved adoption of new technologies (e.g. for an overview, see Landry et al. 2002; for applications to Africa Boahene et al. 1999; Bandiera and Rasul 2002; Isham 2002). A study by Ahlerup et al. (2009) suggests that social capital and formal institutions are each other's substitutes in development, so that social capital is especially important for the poorest countries such as those in Sub-Saharan African where formal institutions are of relatively weak.

Microanalyses of the role of social capital in Africa confirm its important economic role, and its significance when formal institutions are weak (e.g. Narayan and Pritchett 1999; Bigsten et al. 2004; Fafchamps and Minten 2002). For instance, a positive experience in Machakos, Kenya, shows how social capital serves private assets by which farmers could access resources and services that were formerly subjected to high transaction costs in soil conservation (Nyangena 2008). In addition to tenure security and social capital, this paper explores other plot-, farm-, and household-level determinants of soil conservation.

Traditionally, large-scale investments in soil and water conservation are associated with high investment costs and external effects, which would explain the perceived need of the state and NGOs to intervene. Indeed, historically it appears as if large-scale terracing requires a certain level of top-down planning. This intervention approach invested more in labour pooling for soil conservation and less in social and human capital creation (Sidibé 2005). As Pretty and Ward (2001) put it: 'international agencies, governments, banks, and NGOs must invest more in social and human capital creation, and to ensure the transition is made from dependence to interdependence, which in turn helps to build assets'. Clearly, past interventions were involved less in strengthening social arrangements between farmers in order for them to address soil erosion problems by their own institutions. This explains, at least partially, why past interventions in soil and water conservation failed (Hurni et al. 2008; Graaff 1996).

Overview of Bench Terracing in Rwanda

Bench terracing was introduced in Rwanda in the 1970s. Other SWC techniques had been established earlier, such as hedgerows and progressive terraces (trenches coupled with hedges). Both bench and progressive terraces received a lot of attention from different development interventions in agriculture. Establishing these terrace structures requires a few topographical criteria, including angle of slope. A bench terrace is constructed by breaking up the slope (with a gradient of 25–55 %) into different segments in order to maintain the top soils, which are rich in nutrients, and to keep the riser of the terrace intact. Progressive terraces result from tillage practices combined with the planting of hedgerows over a certain period of time, and they are recommended on plots that are less steep (12–25 % gradient). These two techniques differ partly in terms of effectiveness to counter run-off, soil erosion control, capacity to conserve water, and the time needed to change soil properties (Kannan et al. 2010). Mountainous areas similar to most parts of Rwanda are very sensitive to rain erosion. In the short term, bench terraces are deemed to be more effective technically at soil erosion control than progressive ones (Posthumus and Stroosnijder 2010). The layout or ‘bed’ of progressive terraces takes longer to form (about 7 years); this explains their technical effectiveness in the long run (Hudson 1988). Nevertheless, bench terraces call for substantial material and labour inputs in the early, installation stage compared to progressive terraces (Hurni et al. 2008).

The history of bench terraces in Rwanda is linked to state policies and regulations and to interventions by NGOs (Bizoza and Hebinck 2010). The approach used to promote these terraces has shifted over time from top down to somewhat participatory. Various development policies promoted by the current government, such as the ‘performance contracts’ (known as *Imihigo*), collective communal work (*Umuganda*) and *Agasozi Ndatwa* (literally meaning a ‘model hill’), entail certain aspects of community-based development, promotion of farmers’ associations and co-operatives, and a self-reliance mentality towards rural development. In the case of soil and water conservation, these policies are geared primarily towards collective awareness and soil erosion control. At the same time farmers operate in small-scale associations and co-operatives from which different forms of social capital originate (e.g. trust, co-operation, and mutual assistance or reciprocity).

Apart from government interventions, NGOs such as World Vision International played prominent roles in the construction of terraces in the period after the 1994 war and genocide in Rwanda (Bizoza et al. 2007). Bench terraces were constructed in some areas using food support from the USAID. The food-for-work programmes have been contested in the literature for nurturing a dependency mentality, among other effects (Bunch 1999: 216). Material incentives and the commoditization of labour may have created paternalistic behaviour and possibly distorted the real sense of existing local institutions such as mutual support (Newbury and Newbury 2000).

Despite efforts and progress made, the soil erosion control remains important. The 2008 National Agriculture Survey (NAS) showed that 62 % of the cultivable area in Rwanda (an estimate of 1.3 million ha) is protected by anti-erosive measures. Furthermore, 4 % of the protected area is provided by bench (radical) terraces compared to 69 % by anti-erosion ditches of which progressive terraces are formed. Kannan et al. (2010) indicate that 93 % of the total potentially cultivable area is positioned on hillsides under rain-fed conditions and, thus, would be sensitive to soil erosion unless measures are taken. With bench terraces being encouraged by policy in the last three decades, why is progress so slow?

From private perspective, bench terracing is not obviously an optimal soil conservation option (Hurni et al. 2008; Saint-Macary et al. 2010). As indicated above, bench terracing leads to higher investments, which take longer for farmers to pay back unless they are coupled with additional, improved agricultural practices (Posthumus and Graaff 2005; Bizoza and Graaff 2010). Since the top soils of these terraces have been disturbed from an early stage, it has resulted in low soil fertility and high inputs. Typically, in places like Rwanda where per capita land holdings are very small (less than 1 ha), farmers hesitate easily to invest in such a technology. Unless measures to use terraced plots effectively are provided by governmental organizations and NGOs, farmers are rational not to construct terraces on small plots, much of which they depend on for their livelihoods. Results from Bizoza and Graaff (2010) in the same research area show that bench terraces built with help of support projects could well have been established on plots that are too large (and thus underused) and on less suitable soils, resulting in less than expected benefits. Equally, the same NAS (2010) showed that 10 % of farm land is uncultivated. This is noteworthy in a land-scarce country such as Rwanda.

Therefore, the government intends to further promote terracing through different public and private initiatives. Hence, it is important to learn more about the characteristics of the adopters and the role of local institutions in fostering adoption. For this purpose, a distinction is made here between bench and progressive terraces to guide policy to tailor future interventions by responding to which types of terrace are demanded by which categories of farmers in rural Rwanda.

Research Methods

The aim here is to analyse the impact of various local institutions on the adoption of bench terraces in rural Rwanda. The hypothesis that we want to test is whether dimensions of social capital matter in the adoption of bench terraces. For this purpose, household-level data were collected among 301 households who also provided plot-level information on 907 plots located in the North and Southern Provinces in Rwanda. Specifically, the research was carried out in areas (sectors) that cover major parts of the Gicumbi (Northern) and Nyamagabe (Southern) Districts of Rwanda.

The survey respondents were obtained from Buberuka Highland and Congo Crete Nil Watershed agro-ecological zones located in the Northern and Southern Rwanda, respectively. These two zones have a similar topography and received relatively more soil and water conservation interventions due partly to higher erosion risks compared to other zones in Rwanda. A stratified and random sampling procedure was used to obtain respondents from areas that are suitable for bench terraces (25–55 % slope level) and those appropriate for progressive terraces (12–25 % slope level). Geophysical criteria such as altitude and slope steepness are the main criteria used. These are well documented in the literature as necessary conditions to establishing physical structures for SWC such as bench and progressive terraces.

The data collected allowed for testing the impact of social capital on the adoption of terraces, controlling for: plot-, farm- and household-level characteristics, and sector-level. Plot-level controls (X) include slope (dummies), plot size, origin (inherited or otherwise), and the walking distance from home to the plot. Farm and household-level factors (W) comprise altitude, farm size, erosion potential, and socio-demographic characteristics of the heads of sample households (gender, age, family size, formal and informal education). The sector-level aggregates (Z) consist of support programme (World Vision) and average income (Table 26.1).

Social capital (SC) and tenure security (TS) are the institutional variables of interest. As Krishna (2004) points out, ‘it is not easy to observe social capital; people carry it inside of their heads’, making it difficult to measure and to associate it with economic outcomes such as investments in bench terraces. Trust and membership to an organization are two indicators often used for empirical measurement of social capital (Glaeser et al. 2002; Krishna 2004). Accordingly, social capital can be divided into two categories: cognitive social capital (SC_1), manifested by trust and participation in collective labour teams, and structural social capital (SC_2), observed through membership of voluntary organization(s).

In order to measure trust, the survey asked the following question: Do you trust any of the following categories of people: household members, members of the extended family, neighbours, people in the community, local leaders, and leaders of their respective churches? All these stakeholders inter-relate with farmers in the adoption process of new technologies. More specifically, they constitute channels of extension services provided by development officials and hence they are expected to induce farmers adopt or disadopt depending on how they trust them. Trust was coded on a four-point scale, ranging from 1 (‘not at all’) to 4 (‘very much’).

The survey questionnaire asked also whether terraces had been constructed through collective labour, in order to measure its effect on the adoption of terraces. Labour is a major component of investments in bench terraces; and social capital is considered important in playing an economic role in labour markets (Knight and Yueh 2008). Collective action aimed at pooling labour to construct terraces at the individual plot level is regarded to be an alternative asset for farmers in addressing labour constraints for soil conservation and probably with regard to other farming constraints as well (Meinzen-Dick 2009). Hence, a positive and conducive effect of collective action on investment in terraces is expected here.

Membership of associations is an important local institution expected to have a positive effect on the adoption of bench terraces. Farmers join their associations for a variety of reasons, such as mutual support (reciprocity), access to input credit, training, and sharing of agricultural implements. Therefore, farmers who are members of associations are more likely to share experiences and pool resources, which, in turn, might allow them to adopt terraces on their private lands. The government also encourages membership to farmers’ co-operatives. In addition, due to the increasing cognizance of the role of women in rural social and economic life, women-based organizations are taken into account. Hence, the survey asked whether the respondent was a member of any of these voluntary organizations (Yes/No).

Table 26.1 Summary statistics of variables fitted in the analysis of adoption of bench and progressive terraces

Explanatory variables	Description	Obs.	Mean	SD
Institutional Factors (**SC**)				
Trust the community	Average score of community trust (1 = not all and 4 = very much)	301	3.42	0.38
Collective action	Equals 1 if the plot has been terraced through collective action	907	0.06	0.24
Association membership	Equals 1 if a farmer is a member of the association and 0, if otherwise	300	0.33	0.47
Tenure security (**TS**)	Equals 1 if a farmer perceive land secured in the future and 0, if otherwise	301	0.83	0.37
Plot controls (**X**)				
Steep Slope	Equals 1 if the slope of the plot (s) is steep and 0, if otherwise	907	0.21	0.41
Gentle Slope	Equals 1 if the slope of the plot (s) is gentle and 0, if otherwise	907	0.55	0.49
Plot size	Size of the plot in are (1 are = 0.01 ha)	907	35.94	107.8
Inheritance	Equals 1 if a farmer inherited the land and 0, if accessed the land by other means	299	0.62	0.48
Distance	Distance from home to the plot in minutes	907	12.92	17.05
Farm and Household characteristics (**W**)				
Altitude (m a.s.l)	Average altitude of the sub-catchment/Village	301	2,103	163.34
Farm size	Total farm sizes in Ares (1 are = 0.01 ha)	301	107.4	255.46
High erosion potential	Equals 1 if the household is located in an area with high risks of erosion	301	0.14	0.35
Moderate erosion potential	Equals 1 if the household is located in an area with moderate risks of erosion	301	0.32	0.46
Female head	Equals 1 if female and 0, if otherwise	301	0.50	0.50
Age	Number of years old of the head of household	299	43.37	13.59
Family size	Total family members	301	5.73	2.07
Formal education	Years of formal education completed	301	2.75	3.18
Informal education	Equals 1 if a farmer has received agricultural training/field	301	0.31	0.46

(continued)

Table 26.1 (continued)

Explanatory variables	Description	Obs.	Mean	SD
	visit/ extension meeting and 0 if otherwise			
Total Livestock Unit (TLU)	Cattle size (=0.8), pigs (=0.2), sheep and goat (=0.1)	301	1.25	1.19
Sector-level variables (**Z**)				
Programme support	Equals 1 if a farmer is from a sector supported by World Vision International	301	0.41	0.49
Average Sector-level Income	Average of income per sector	301	68,640	45,575
District	Equals 1 if the plot (family) is located in the North and 0, if the Southern region	301	0.55	0.49
Dependent Variables				
Adoption of bench terraces (BTA)	Equals 1 if a given plot (family) has bench terraces and 0 if otherwise	907	0.32	0.47
Adoption of progressive terraces (PTA)	Equals 1 if a given plot (family) has progressive terraces and 0 if otherwise	907	0.28	0.45

Tenure security (TS) is another institutional dimension expected to influence the decision to invest (or not) in terraces (Deininger and Jin 2006). Land titling is still going on in Rwanda. The survey included a question about perceived tenure security, whether the respondent(s) thought that he/she would continue to use the land during their lifetime. Table 26.1 describes other independent and dependent variables identified in the model.

Data have been analysed at plot level. It is possible for a given household *i*) to have more than one plot (*k*) with variant physical characteristics and household-specific variables. Probit ML estimator has been applied (Wooldridge 2002), with robust standard errors clustered at household level in order to estimate our adoption model specified as Eq. 26.1. A district dummy (Z) was included in variables to control for potential heterogeneity between the two districts in the study area. The dependent variable *Y* stands for either bench terrace adoption (BTA) or progressive terrace adoption (PTA).

$$Y_{ik} = \alpha + \beta_1 SC_{1i} + \beta_2 SC_{2i} + \beta_3 TS_i + \gamma_1 X_k + \gamma_2 W_i + \gamma_3 Z_c + \varepsilon_{ik} \qquad (26.1)$$

Where *i* indexes the household, *k* stands for the plot, while *c* denotes sector-level variables. Y_{ik} stands for dependent variables BTA and PTA with $Y_{ik} = 1$ if adoption occurs or $Y_{ik} = 0$ in the case of non-adoption. SC_{1i}, SC_{2i}, TS_i, X_k, W_i and Z_c are the vectors of observable explanatory factors as described above, while β_i is a vector of estimated coefficients. Finally, ε_{ik} is the error term, which is assumed to be random.

Endogeneity of regressors is not of concern for the geographical variables since they are given. However, some of the institutional measures, namely trust, tenure security (TS) and association membership, are potentially endogenous. The standard Durbin-Wu-Hausman (DWH) test was applied to investigate whether exogenous variation in these factors could be identified (Cameron and Trivedi 2009). The difficulty in the use of instrumental variable approaches when establishing the causal effects of social capital is finding relevant and valid instruments (Knight and Yueh 2008). This is the case for the 'trust' variable. Alternatively, average scores of community trust were used, which are less likely to be correlated with individual residuals. Another option is to compute trust and association membership scores at household level using factor analysis (Narayan and Pritchett 1999; Nyangena 2008). These scores were loaded and tested in the analysis. Only the trust index has both positive and significant associations with BTA. However, reported results are those with an average score for community trust. The DWH test for endogeneity of tenure security (TS) and association membership resulted in a strong acceptance of the null hypothesis that TS ($F(1{,}300) = 0.697208$; ($p = 0.4044$)) and association membership ($F(1{,}300) = 0.700373$; ($p = 0.4033$)) are both exogenous. Therefore, the assumed endogeneity of tenure security and association membership variables is no longer a problem. Hence, they can be identified in the regression analysis.

Empirical Results

Two equations have been considered: one for bench terrace adoption and one for the adoption of progressive terraces. The purpose is to examine what factors determine adoption of bench and progressive terraces, with a focus on local institutions. Obtained coefficients are based on robust and clustered standard errors at household level. The marginal effects of the explanatory variables are computed at their sample means.

Table 26.2 presents results from the analysis of BTA. The results show that, among the three sector-level variables (Z), the coefficients of sector-average income and district dummy suggest positive impacts on the adoption of bench terraces (both significant at the 1 % level). The inference is that higher income farmers are more likely to adopt bench terraces compared to those with a low income. The dummy coefficient indicates that farmers in the Northern province have adopted more bench terraces compared to those in the Southern province. This outcome is in line with expectations. Bench terracing started in the Northern Province before being introduced in the Southern Province, which provides a partial explanation of the difference. Surprisingly, World Vision's support programme, although positive, proved to have no significant association with the adoption of bench terraces. This is difficult to explain. A possible answer can be found in the higher number of samples (about 65 %) used in the analysis from random sectors that did not receive much support from World Vision for bench terrace construction.

Table 26.2 Probit regression of adoption of bench terraces with robust standard errors (clustered at household level)

	Bench terrace adoption (BTA)	
Variable	Coefficient (robust Std. Dev)	Marginal effect
Institutional factors (SC)		
Trust	0.408 (0.132)***	0.141
Association membership	−0.182 (0.126)	−0.061
Collective action	2.136 (0.297)***	0.678
Tenure security (TS)	0.104 (0.137)	0.035
Plot Controls (X)		
Steep Slope	0.489 (0.169)***	0.178
Gentle Slope	0.339 (0.133)**	0.115
Plot size (Log)	0.157 (0.052)***	0.054
Inheritance	−0.223 (0.104)**	−0.077
Distance	−0.021 (0.004)***	−0.007
Farm and household level variables (W)		
Altitude (m a.s.l)	0.002 (0.000)***	0.0007
Farm size	−0.104 (0.068)	−0.036
Higher erosion	−0.648 (0.151)***	−0.193
Moderate erosion	−0170 (0.120)	−0.057
Female head	−0.534 (0.121)	−0.052
Age	−0.013 (0.023)	−0.004
Age (squared)	0.0001 (0.000)	0.00002
Formal education	0.001 (0.019)	−0.0004
Informal education	0.315 (0.133)**	0.111
Family size	0.058 (0.034)*	0.020
Total Livestock Unit (TLU)	0.013 (0.056)	0.004
Sector-level variables (Z)		
Programme Support	0.105 (0.129)	0.036
Average sector-level income	4.07E-06 (1.24E-06)***	1.42E-06
District	0.577 (0.138)***	0.190
Constant	−6.630 (1.163)***	
Regression diagnostics		
Log Likelihood	−430.754	
Chi-square (23)	193.49	
Probability > Chi-square	0.0000	
Pseudo *R*-square	0.2494	
Predicted Probability at mean	0.294	
Sample size (*n*)	906	

$^{*}P < 0.1$; $^{**}P < 0.05$; $^{***}P < 0.01$

Some farm and household-level variables (W) correlated with the adoption of bench terraces at different critical levels: altitude, high potential erosion, informal education, and family size. Farmers with plots located in mountainous catchment areas with high potential erosion were more likely to adopt bench terraces for easy cultivation of steep plots and to protect the soil from run-off than farmers in the lowlands (significant at the 1 % level).

Formal education is specified in most of literature as conducive to adopting conservation agriculture (e.g. Graaff et al. 2008; Diagne and Demont 2007; Dimara and Skuras 2003; Mbanga-Semgalawe and Folmer 2000). However, this does not apply to most cases (Knowler and Bradshaw 2007). A possible explanation lies in the assumption that number of years of education correlates strongly with decision to adopt. In small-scale and traditional farming practices such as in Rwanda, it is difficult to believe that formal education plays a major role (Welch 1978). For instance, it is debatable whether a sample farmer with an average age of 43 and with 3 years of primary education will rely on the knowledge obtained back at primary school after 34 years (assuming he or she started primary education at 6 years old). Instead, informal education explains most of the adoption of conservation technologies such as bench terraces (significant at the 5 % level). Therefore, it is more likely that farmers adopt because of the experiences they share with neighbours, the training they receive, and their contacts with extension officials.

Characteristics of the plot such as gradient level and plot size, mode of land access, and the distance from home to the plot matter in a farmer's decision to invest in soil and water conservation. Bench terraces were established on steeper plots (gradient levels of 25–55 %). While progressive terraces are supposed to be established on plots with slope percentages of 12–25 %, in this research both slope categories (steep and gentle) are correlated positively with the adoption of bench terraces (significant at the 5 % level). To some extent, this reflects insufficient technical consideration at an early stage of terrace construction. The estimated positive coefficient of plot size has an important effect on soil and water conservation investments (significant at the 5 % level). Plot size together with steepness of the plot may affect the width and the length of a terrace, and thus the choice of whether or not to adopt, all else being equal.

Distance from home to the plot discouraged investment in soil conservation (significant at the 1 % level). Clay et al. (1998) found a similar result in their Rwandan study. The more remote a given plot was from the homestead, the greater the transactions costs expected, especially when farmers relied on transporting residues and other inputs from their homesteads to the farms on their heads. The security issue seems relevant in this situation. The correlation between tenure security and distance from homestead to the plot was tested and it was found negative and not statistically significant (even at the 15 % level).

From the above, it does appear that farmers respond to economic incentives. In spite of the evidence that the cost–benefit ratio for investing in bench terraces is not very favourable, farmers do seem to focus their terracing efforts on the plots they use most intensively: plots close to the house and plots with the highest labour intensity.[1] Results from the T-test confirmed that terraced plots received more labour inputs compared to unterraced or progressively terraced ones ($t = -6.28$; significant at the 1 % level). This is consistent with Bizoza and Graaff (2010), who

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[1] Labour allocation per plot (excluding labour for terrace construction) was rejected in the estimation as it was found to correlate positively and strongly with BTA (at the 1 % level).

reported that not all terraced plots were cultivated and that labour costs constituted a major part of the operating costs in rural Rwanda. Therefore, comparison of bench terraces with other soil conservation techniques will show that better consideration of labour requirements is critical for cultivation, terrace construction costs, and maintenance (Dehn 1995).

Customary land tenure is dominant in Rwanda. Often, family inheritance systems determine how people access land in Rwanda and elsewhere in Africa (André and Platteau 1998). The majority of the samples in this research accessed their land through inheritance (62 %) and few purchased (26 %). Equally, the 2008 National Agricultural Survey reported that 46 % of the households accessed their land through inheritance compared to 25 % who bought their lands. Our empirical evidence indicates that the more the land (plot) is inherited, the lower the adoption probability of bench terraces (significant at the 5 % level). Meanwhile, vast claims have been made in the literature for the need for individualization and registration of plots in Rwanda (ref). The government has initiated a process of land registration and the issuance of formal land rights. However, this may not be necessarily inducing investments in land conservation. There is little empirical evidence from similar contexts in Africa and other developing countries to support the position that formal land titling or traditional rights have increased investment in agriculture (Barrows and Roth 1990; Saint-Macary et al. 2010). Hence, whether formal or traditional land rights are conducive to the adoption of soil conservation measures should be considered context-specific and remains open to empirical debate in Rwanda.

The analysis on the effect of institutions on bench terrace adoption showed a positive association between some of the measures of social capital and an increased probability to invest in bench terraces. Trust as part of cognitive social capital (SC_1) was highly conducive to investments in bench terracing (significant at the 1 % level). This is consistent with Bouma et al. (2008), who also maintained that farmers in villages with high levels of trust are likely to contribute willingly to community resource management. Terracing leads to onsite as well as downstream effects that require farmers to act collectively. Efforts by one farmer to invest in bench terraces may be undermined if other farmers up- or downstream do not adopt (Nkonya et al. 2008), thus calling for collective adoption. In such a situation, social capital will ease co-operation among people for them to work collectively. One believes that others will reciprocate and also contribute to the public good. The research also showed that collective action in the form of labour pooling, another measure of SC_1, had a positive association with the adoption of bench terraces (significant at the 1 % level). This had been expected. As noted earlier, building a terrace is a tedious task that is best done in a group. Living in a community where such forms of co-operation occur helps in the construction of terraces, a task much more difficult for individuals to perform on their own.

Surprisingly, the effect of structural social capital (SC_2), represented here by membership of farmers' associations, was zero. This outcome stands in contrast to other empirical findings from previous studies where membership of associations had positive and significant associations with investment in soil conservation (e.g. Nyangena 2008; Rezvanfar et al. 2009). Farmers receive services from their organizations, including information about the need for terracing. Typically, these organizations are multipurpose in nature. It is, therefore, possible for someone to be a member of an organization without necessarily having to adopt bench terraces, *ceteris paribus*.

Tenure security (TS) did not explain bench terrace adoption (BTA). The results contrast with earlier studies that maintain that tenure security favours long-term investments in SWC (Nyangena 2008; Shiferaw and Holden 2001; Gebremedhin and Swinton 2003). Two offsetting effects might explain this outcome: (i) farmers can invest in soil conservation measures when they feel they have tenure security, or (ii) they can invest in order to achieve tenure security for their landholdings. There are no formal titles in Rwanda although the land titling process is ongoing. Nevertheless, about 80 % of the survey respondents felt they had secure land tenure – these are people farming plots that they inherited from their fathers compared to farmers who had purchased plots (holding deeds) or who had accessed plots by other means. In addition, the need to secure land is justified mainly when risk of appropriation is significant or when better land markets exist. None of these two cases are evident in the study area, which explains the low impact of tenure security in the adoption of bench terraces in Northern and Southern Rwanda. In conclusion, farmers need to feel their land is secured when they have made substantial investments; however, this requires additional measures such as credit subsidies to improve the capacity to invest in terraces.

Overall, results from the analysis mirror the growing academic debate that local institutions matter in the adoption of soil and water conservation. However, not every dimension of the institutional framework (as specified) is found to be important in the Rwandan case. Trust and collective action are instrumental in explaining terrace adoption. There is no empirical proof that the adoption of bench terraces can be explained through association membership or tenure security justify, although this is relation is assumed important in policy and other researches. Therefore, results show that local institutions affect the adoption of bench terraces and that they can serve for alternative resources for farming implements in poor-based economies such as Rwanda.

Results of the progressive terrace adoption (PTA) are presented in Table 26.3. Only six of the variables used are significant in explaining the adoption of progressive terraces. Sector-level estimates (Z) of programme support (by World Vision) and the district dummy suggest increased probability of PTA (significant at the 5 % and 1 % levels, respectively). Average sector income was not significant, which suggests that farmers in areas with higher than average incomes were likely to prefer BTA over PTA, under *ceteris paribus* conditions. Contrary to the outcomes of the analysis of BTA, programme support explained PTA (significant at the 5 % level). A possible reason could be the World Vision International Rwanda's recent development strategy to promote progressive terraces after recognizing that some of constructed bench terraces were too expensive for farmers to use.

Among the farm and household variables (W), distance from home to the plot and plot altitude correlated with PTA. These variables are estimated with their

Table 26.3 Probit regression of adoption of progressive terraces with robust standard errors (clustered at household level)

	Progressive terrace adoption (PTA)	
Variable	Coefficient (robust Std. Dev)	Marginal effect
Institutional factors (*SC*)		
Trust	−0.163 (0.122)	−0.052
Association membership	0.010 (0.121)	0.003
Collective action	−0.069 (0.232)	−0.021
Tenure security (TS)	0.118 (0.148)	0.037
Plot Controls (X)		
Steep Slope	−0.254 (0.143)*	−0.078
Gentle Slope	−0.055 (0.118)	−0.017
Plot size (Log)	0.164 (0.048)***	0.053
Inheritance	0.105 (0.097)	0.033
Distance	−0.009 (0.003)***	0.003
Farm and household level variables (*W*)		
Altitude (m a.s.l)	0.002 (0.0003)***	0.0007
Farm size	−0.095 (0.074)	−0.031
Higher erosion	0.193 (0.147)	0.065
Moderate erosion	0.189 (0.122)	0.062
Female head	0.171 (0.115)	0.0554
Age	−0.008 (0.025)	−0.003
Age (squared)	0.00007 (0.000)	0.00002
Formal education	−0.008 (0.017)	−0.002
Informal education	0.181 (0.121)	0.059
Family size	−0.028 (0.028)	−0.008
Total Livestock Unit (TLU)	−0.084 (0.054)	−0.027
Sector-level variables (*Z*)		
Programme Support	0.292 (0.132)**	0.095
Average sector-level income	−2.07E-06 (1.37E-06)	−6.70E-07
District	0.807 (0.141)***	0.244
Constant	−5.287 (0.994)***	
Regression diagnostics		
Log Likelihood	−485.904	
Chi-square (23)	116.04	
Probability > Chi-square	0.000	
Pseudo R-square	0.1007	
Predicted Probability at mean	0.258	
Sample size (n)	906	

$^{*}P < 0.1$; $^{**}P < 0.05$; $^{***}P < 0.01$

expected signs and the implications of results is the same as for BTA. Among the plot-level variables, only plot size is instrumental in explaining PTA (significant at the 1 % level). Therefore, plot size matters when considering investing in either BTA or PTA.

Of the institutional variables, neither trust, collective action, association membership nor tenure security explained adoption of PTA. Since progressive terraces are build slowly because of tillage and use of hedges, reciprocity in pooling labour or sharing agricultural implements is less common compared to bench terracing. Trust lubricates co-operation in situations where reciprocity in sharing labour and implements prevails (Pretty and Ward 2001). Similar to the results in the analysis of BTA, there was no empirical evidence that association membership and land tenure security encouraged PTA.

In summary, the empirical results reflect that social arrangements are necessary in order to establish bench terraces but not for progressive terraces. The marginal effects (at sample mean) of trust ($dy/dx = 0.141$) and collective action ($dy/dx = 0.678$) suggest social capital an alternative asset(s) to be taken into consideration when investing in bench terraces in Rwanda. That is, farmers in areas endowed with high levels of social capital are likely to adopt bench terraces when the government and NGOs decrease or stop their interventions (Bouma et al. 2008; Ahlerup et al. 2009).

Conclusions

In this study, the role of local institutions, among other factors, is considered in the adoption of bench terraces in rural Rwanda. The results of the analysis sustain the ongoing discourse that social capital maters for soil and water conservation. Soft institutional factors – trust and the ability to co-operate in collective action – affect the adoption of bench terraces more than ‘hard’ ones – association membership. None of the local institution variables explain adoption of progressive terraces. Furthermore, perceived tenure security does not explain adoption of either bench terraces or progressive terraces. This may be due to the peculiar nature of the case study, where informal (customary) tenure rights still play an important part.

Another significant insight from the analysis is that farmers do want to have terraces and allocate their best plots for this purpose – plots that are large in size, close to the house, and intensively cropped. On the other hand, it is revealed that some farmers are unable to secure complementary materials and labour inputs. Consequently, some fail to use effectively their terraced plots. For example, this case-study proves that about 10 % of smallholders abandon their terraced plots or fail to use them productively. In addition to the promotion of terracing, interventions by NGOs and policy-makers should also focus on the sociocultural settings in the early stage of soil and water conservation measures. In poverty-based economies such as Rwanda, local institutions can supplement government and NGO investments in soil and water conservation. Farmers can construct terraces themselves through their own local institutions. This does not imply total withdrawal of state involvement in soil conservation, but the need for the state to co-operate with local institutions in a variety of innovative ways to sustain complementarity. Therefore, government and NGOs need to allocate further investments in the consecutive use of established terraces than in the construction of new ones.

Results show also that bench terraces were constructed on plots with either gentle or steeper slopes. Farmers need more training before they embark upon the terracing process to ensure technical efficiency and sustainability of established terraces. Finally, the above findings confirm the hypothesis that local institutions play an important role in the adoption of bench terraces in rural Rwanda. More research is needed to advise how these social arrangements can play better their roles and into the extent to which they can supplement or even substitute direct interventions by NGOs and the state in soil and water conservation on private land in Rwanda.

Returning to the research results, some general lessons can be drawn about the role of institutions on the adoption of new agricultural technologies. *First*, the effect of tenure security on a farmer's decision to invest in agricultural technologies should be analysed with caution, especially in developing countries similar to Rwanda. Land tenure security does depend also on the interaction with other factors such as land governance, credits and markets in agriculture. Moreover, measuring the extent to which farmers feel they have tenure security, often with a single binary indicator, seems oversimplified to accommodate confounding effects of such factors on land tenure in microanalysis. This could be reason why the effect of land tenure on the adoption of technology is found to be insignificant in most studies as above referred. Especially in Africa, costly soil conservation measures such as bench terraces involve public interventions that, in many cases, may be calculated into private decision-making to adopt such soil conservation measures. Therefore, proper analysis of the role of tenure security in adoption of soil conservation is expected at government or institutional level rather than micro-economic analysis such analysis lies beyond the scope of this paper.

Second, there is a general claim in recent literature that membership of farmers' organizations is conducive to natural resource management. However, membership can also predict a range of social capital measures It is assumed invariably that farmers may gain through membership many kinds of support from government and NGOs, such as credit, training, sharing of agricultural implements, including labour pooling to erect soil conservation structures. Moreover, farmers' organizations provide an intermediary layer of institutional arrangements through which extension and other development agents operate. Therefore, better analysis of membership needs to open up this 'black box' and investigate the extent to which farmers gain (or lose) assumed benefits from membership. This will explain much better the role of membership of farmers' organizations in soil conservation and rural development in general.

The paper's outcomes are relevant for policy and research options in land conservation. Measuring the impact of local institutions on the adoption of terraces allows the Rwandan government to tailor further investments in land conservation to existing social and institutional arrangements at the local level.

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Part IV
Knowledge-Intensive Approaches

Chapter 27

Beyond the Pilot Sites: Can Knowledge-Intensive Technologies Diffuse Spontaneously?

Evelyne Kiptot

Abstract Rapid and cost effective transfer of knowledge-intensive agricultural technologies is of paramount concern to research and development organisations. However, very little information exists on whether such technologies can diffuse spontaneously from pilot sites. This study sought to examine the diffusion and adoption of improved tree fallows and biomass transfer technologies in villages neighbouring pilot sites in western Kenya. Pilot sites refer to villages where an agroforestry programme worked with farmers to test and disseminate knowledge-intensive agroforestry-based soil fertility management technologies using a community-based participatory approach. Data in non-pilot sites was collected through household interviews and observations. Findings of the study show that although there was spontaneous diffusion of the technologies, a substantial number of farmers who heard about the technologies never adopted. The low adoption was attributed to insufficient knowledge to implement the practices, lack of immediate tangible benefits and insufficient resources such as land and labour. Spontaneous diffusion was mostly through informal social networks such as neighbours and relatives which were not sufficient on their own to enhance the adoption of the knowledge intensive technologies. A conducive context, extensive social networks and technical support are important determinants for spontaneous diffusion and adoption to take place.

Keywords Spontaneous diffusion • Non pilot villages • Improved tree fallows • Biomass transfer

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Introduction

In 1928, hybrid corn was released to farmers by the Iowa State Agricultural Experiment station in the United States. Despite its superior yields over the traditional corn and intensive promotion by the extension service and seed companies, hybrid seed initially had a slow rate of adoption, but was eventually taken up widely by Iowan farmers. The events that followed thereafter, culminated in a study by Ryan and Gross (1943) in which they investigated the diffusion of hybrid corn among farmers in Iowa and that of Griliches (1960) who investigated the economics of innovation. The findings of these initial studies have influenced the methodology, theoretical framework, and interpretation of research on diffusion and adoption of technologies all over the world. The two studies revealed three key points: (i) that the adoption process began with a few farmers, and only later did the innovation spread to other farmers, (ii) the most influential source of information on this innovation was neighbours, and (iii) that the adoption of new technologies is a series of events, that occur at different rates across geographical space with farmers making individual decisions and economic calculations that influenced their decision making. This work, followed by that of Rogers (1958), has provided the basis for diffusion of innovation theory that has influenced how agricultural extension has been conducted. According to this theory based on a linear transfer of technology model, innovation and their attributes are given, and potential users are expected to adopt the technology. For those who did not adopt, change agents were supposed to pursue them to change attitudes, with the hope that the laggards would one day adopt (Rogers 1995).

The extension system in most countries, Kenya included was modelled around the diffusion of innovation theory. Innovative technologies developed by researchers in research stations were transferred to contact farmers who were expected to serve as model farmers so that other farmers in the community could learn from them with the output of widespread adoption. But a lot has changed since then. Change occurred after it was realised that the model did not take into account farmer innovations and that the non-adopters were not recognised (Yapa and Mayfield 1978). The approach was biased towards wealthier farmers, who in most cases did not interact much with other community members (Gautam 2000). These criticisms led to a radical shift in research and development, which has seen the extension system transform from the linear model of technology transfer to a current focus on participatory approaches and demand-driven extension. These approaches are more interactive and iterative, encourage farmer innovations, and above all consider farmers as key stakeholders in the whole process of technology development and dissemination. There has also been a change in extension policy in many developing countries from material delivery and incentive package provision to demand driven extension (Christoplos 2010). Furthermore, the role of extension has also changed from providing blueprints to offering facilitation (Davis 2006).

Although the extension system in Kenya has changed its mode of operation, from top-down to bottom-up, this change has not had much impact on small-scale farmers. This is due to a number of factors that include the structural adjustment programmes imposed by the International Monetary Fund in the early 1990s which led to financial constraints stretching Ministry staff and services very thinly (Kiptot et al. 2006). Because the number of extension officers has been reduced considerably, the few on ground are not able to reach the many farmers who need extension services (Gautam 2000). According to participatory poverty assessments conducted in ten districts of Kenya in 2000, it was found that lack of extension services are partially to blame for poverty (Republic of Kenya 2001a). In order to address this problem, more attention is being given to new pluralistic approaches, which are seen as a more feasible method of technology development, dissemination, and up-scaling. These approaches, which are participatory in nature, involve many actors and promote farmers as the principal agents of change in their communities. They focus on enhancing farmers learning processes and capacity building. They work on the assumption that if one farmer adopts a technology successfully, others may learn from him/her, thereby increasing the spread of technology (Sinja et al. 2004).

One such approach used in western Kenya to disseminate information on agroforestry is known as the village committee approach (VCA) (Noordin et al. 2001). The VCA is a strategy to involve farmers fully in the technology development and dissemination process so as to arrive at better adoption by farmers. The assumption of this approach is that technologies developed jointly between farmers and researchers, and taken up by participating farmers in pilot sites, will indeed diffuse spontaneously and be adopted by other community members in other villages not directly involved in the participatory process, thereby making the process sustainable. The approach was tested on a pilot basis in 17 villages in western Kenya and it was assumed that technologies would diffuse from these villages to neighbouring ones. But agroforestry-based soil fertility management technologies are quite complex and require a lot of understanding before implementation. Furthermore, in the case of hybrid corn, there was strong promotion by the extension service at the grassroots. The same cannot be said of agroforestry-based soil fertility management technologies. This is because the state extension service in Kenya is not effective and therefore agroforestry technologies are expected to diffuse spontaneously to farmers in non-pilot villages.

There are a number of issues that further complicate the diffusion process such as (i) agroforestry technologies for soil fertility replenishment such as developed in western Kenya do not have immediate benefits and farmers have to wait 2–3 years before they see returns and (ii) the technologies are knowledge intensive and therefore involve knowledge transfer and much learning before implementation. So the main question is "can complex technologies diffuse spontaneously without technical support from the extension service?" Is there indeed diffusion and to what extent? Does diffusion of the technology reflect the adoption process? What are the diffusion channels of a technology in the community? Which ones are more popular and why? This study sought to examine these issues by conducting a survey in four villages neighbouring the pilot villages, but not in any way involved in the participatory process of agroforestry technology development.

Background About Improved Fallows and Biomass Transfer in Western Kenya

Research on agroforestry for soil fertility improvement in western Kenya began in the late 1980s, after the World Agroforestry Centre (ICRAF) carried out a diagnostic study in the area that found that low soil fertility was a key problem influencing crop productivity (Minae and Akyaempong 1988). Drawing from this evidence, ICRAF in collaboration with the Kenya Forestry Research Institute (KEFRI) and the Kenya Agricultural Research Institute (KARI) established a research programme in western Kenya in 1988 to address soil fertility problems. Research on improved fallows began in 1991. Fallowing of land has always been part of the farming system in western Kenya. However, pressure on land has forced most farmers to reduce their fallow periods (Minae and Akyaempong 1988). These shortened fallows could no longer restore the fertility of the soil, hence the promotion of improved tree fallows which are regarded as a valuable, low-cost option for restoring soil fertility in Africa (Niang et al. 1998). Instead of letting the natural vegetation develop freely, selected leguminous trees/shrubs or cover crops are planted at high density to replenish soil fertility. Screening trials undertaken in the 1990s resulted in the selection of new species that had a short life cycle (6–18 months). The species that were found promising were: *Crotalaria grahamiana*, *Tephrosia vogelii, Tephrosia candida*, *Crotolaria paulina*, *Crotalaria striata*, *Crotolaria ochroleuca* and *Crotolaria agatiflora* (Niang et al. 1998). These shrubs were found to bring about impressive maize yields as well as providing fuel-wood and reducing *Striga* weed (*Striga hermonthica*).

Additionally, in the mid-1990s testing of locally available shrubs was done in collaboration with the Tropical Soils Biology and Fertility Programme (CIAT-TSBF) to look at their potential to supply nutrients to maize crops in a cut-and-carry system. One species, *Tithonia* (*Tithonia diversifolia)* was found to be the best bet among several because of its ease of establishment, easy handling (free of thorns or sharp leaves), high concentrations of nitrogen (N), phosphorous (P) and potassium (K) in its leaves, and good yield impact on crops (Jama et al. 2000). In the beginning, *Tithonia* leaves were gathered from roadsides or farm boundaries and applied to plots at planting time. Later, a whole range of management options were explored by farmers, but in all cases, a system of biomass transfer was practiced (growing the shrub in one place and applying the biomass in another), hence the name, biomass transfer technology.

After a few years of on-station trials, the two technologies (improved fallows and biomass transfer) were taken to farmers' fields on a trial basis in researcher designed/farmer managed trials. In the mid-1990s, this evolved into farmer-designed/farmer-managed trials where farmers were invited to try out some of the species on their farms. Regular monitoring was undertaken at various stages of experimentation and adaptation (Noordin et al. 2003). In 1997, the agroforestry programme embarked on wide-scale dissemination using the village committee approach (VCA) in 17 pilot villages of Vihiga and Siaya Districts.

Methodology

Description of the Study Area

The study area is located in the highlands of western Kenya and comprises two villages each in Siaya and Vihiga districts. Farmers have secure rights to their land. The average farm size has been steadily declining; in Siaya it is an average of 1.0 ha while in Vihiga it is 0.5 ha. Maize which is the staple food crop is often intercropped with beans. Rainfall is bimodal, ranging between 1,600 and 1,800 mm per annum, divided between the long rains in March to May and the short rains in September to November. The region has a high agricultural potential with two cropping seasons per year, but low soil fertility is a widespread problem. Food insecurity is high in both districts, with some areas experiencing up to 9 months of food deficiency. A large proportion of the labour force is engaged in agricultural activities which increasingly suffers from labour being drawn into off-farm work elsewhere. Furthermore, high population densities, which have increased over the years, continue to exert enormous pressure on the land. In Siaya, the population density is 310 people/km^2 while in Vihiga district it is 800–1,100 people/km^2 (Republic of Kenya 2001b). Poverty levels in both districts are among the highest in Kenya; in 1994, 53 % of Vihiga district's population lived below the poverty line, and the number increased to 58 % in 1999 (Republic of Kenya 2001a).

Methods of Data Collection and Study Villages

The four villages are Jina and Ulumbi in Siaya and Murumbi and Ekamanji in Vihiga. The household was used as the sampling unit of inquiry, and villages were the primary units selected at the first stage of sampling. The villages were selected randomly from a list of villages in Jina sub-location (3) and Ebusiralo sub-locations (5). A list of households in the villages in the study area was constructed with the assistance of local leaders, i.e., village headmen. Each village was sampled independently to ensure equal representation. A 10 % sample of households was then randomly selected from this list, and as a result a total of 103 farmers were drawn for the interviews.

Since the purpose of this study was to determine the diffusion and adoption of agroforestry technologies, in particular biomass transfer and improved fallows, various methods were used in order to capture the diffusion and adoption process. These were: a formal survey using a pre-designed questionnaire, and observation and where necessary, informal in-depth interviews were followed up with a few informants. This was necessary as farmers perceptions could not be readily captured in the questionnaires.

Results

Whether Farmer Has Ever Heard of Improved Fallows and Biomass Transfer Technologies

Out of 103 farmers who were interviewed from the two districts, Siaya and Vihiga, 43 % had heard of improved fallow technology; however, only 14 % of farmers had ever seen improved fallow technology. As regards to biomass transfer, only 33 % of farmers had heard of it.

What Factors Are Likely to Influence the Spontaneous Diffusion of Agroforestry Innovations?

In order to assess factors that are likely to influence the diffusion of improved tree fallows and biomass transfer technologies, a logit regression model (Table 27.1) was developed.

In the regression model Y1, gender of the farmer had a negative and significant association with the diffusion of the improved fallow technology ($P < 0.10$). The implication for this is that female farmers are more likely to hear about improved fallow technology than male farmers. This could be attributed to the fact that women are known to belong to more farmer groups and therefore have extensive social networks which enhances their awareness of innovations. In the regression model Y2, the age of the farmer had a positive significant association with diffusion of biomass transfer technology ($P < 0.05$), indicating that as farmers advance in age, there are more likely to be aware of biomass transfer technology.

Source of Information About Improved Fallow Technology and Biomass Transfer

Relatives were the most popular source of information (Table 27.2). Other sources of information were public meetings (*Baraza)*, the Ministry of Agriculture, NGOs operating in the area, neighbours and the Maseno Agroforestry Programme in western Kenya.

Table 27.1 A logit regression model of factors that are likely to influence diffusion of improved tree fallows and biomass transfer technologies

	Whether farmer had ever heard of improved tree fallow technology ($Y_{1)}$		Whether farmer had ever heard of biomass transfer technology ($Y_{2)}$	
Parameter	Coefficient	S.E.	Coefficient	S.E.
Gender	–0.940*	0.493	–0.443	0.509
Age	0.006	0.014	0.034**	0.015
Farm size	–0.185	0.254	–0.288	0.278
Ownership of improved cows	–0.252	0.367	0.303	0.349
Membership in group	–0.549	0.461	–0.233	0.483
No. of adults working on farm	0.148	0.290	0.019	0.316
Ability to hire labour	–0.070	0.447	–0.075	0.464
Constant	0.413	1.034	–1.648	1.092
Nagelkerke R^2				
Model $Y_1 = 0.080$				
Model $Y_2 = 0.093$				

NB: Dependant variables: $Y_{1=}$ whether farmer had ever heard of improved tree fallow technology and Y_2 = whether farmer had ever heard of biomass transfer technology (1 = Yes, 2 = No). Definition of categorical independent variables: gender 1 = male, 2 = female, ownership of improved cows, 1 = Yes, 2 = No, membership in group, 1 = Yes, 2 = No, ability to hire labour, 1 = Yes, 2 = No.

*, **significant at 10 %, 5 % level of probability

Table 27.2 Sources of information on improved fallows and biomass transfer technologies

	Agroforestry technology	
	% of farmers (N = 103)	
Sources of information	Improved fallow	Biomass transfer
Neighbours	5	7
Agroforestry programme	4	5
Relatives	28	24
Friends	8	10
Group	6	8
Baraza (Public meetings)	7	2
Ministry of agriculture	2	2
Non Governmental Organisations (NGOs)	3	4
Any other	3	6
None	57	67

NB: There were multiple responses

What Knowledge About Improved Fallows Did Farmers Have?

Those farmers who had heard of improved tree fallows were asked if they had any knowledge about the fallow technology. All 44 farmers who had heard of improved fallows indicated that they were told that the technology is good for soil fertility management. But only 2 % of farmers had an idea of the kind of nutrients that were replenished by improved tree fallow systems. Only 14 % of farmers said that they knew various types of species used for improved fallows. It is also interesting to note that although improved tree fallows were mainly promoted for soil fertility management, a good proportion of farmers (20 %) were told that improved tree fallows were also good for repelling moles. Only 13 % of farmers said that they had knowledge on how to plant an improved fallow, while 15 % indicated that they were told that tree species used for fallows also provided fuel-wood. More than half of the respondents (57 %) had no idea about what improved fallows were.

What Aspects of Biomass Transfer Technology Did Farmers Know?

All farmers (33 %) who had heard about biomass transfer indicated that *Tithonia* was the species most used. A substantial number (20 %) knew various ways of using *Tithonia*. Some mentioned that it can be used to make compost or applied directly as a green manure, used as mulch and as a pesticide. About 18 % knew when to use biomass transfer. Two thirds (67 %) of farmers sampled had no idea whatsoever what biomass transfer was while very few farmers (6 %) had an idea of the kind of nutrients that are replenished when *Tithonia* was used as a source of plant nutrients.

Which Technology Has the Farmer Ever Practiced?

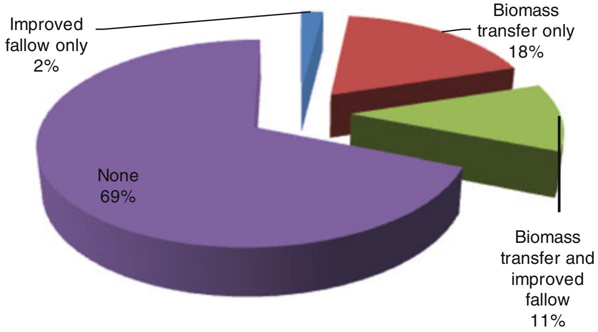
Out of 103 farmers sampled, 19 farmers (18 %) indicated that they have ever practiced the use of biomass transfer technology only while 11 % indicated that they had practiced the use of both biomass transfer technology and improved fallow while a minority (2 %) indicated that they had practiced the use of improved fallow technology only (Fig. 27.1).

There has been low use of both biomass transfer and improved fallow technologies in non-pilot villages. The findings in Fig. 27.2 show that the use of improved tree fallow technology has been declining with more farmers opting to use *Tithonia* for soil fertility management, although the number of farmers is quite low. The use of *Tithonia* in compost seems to be preferred by farmers compared to direct application as green manure (Fig. 27.2). This is due to the fact that using *Tithonia* in compost is less labour intensive compared to direct application as a green manure.

Reasons Why Farmers Who Had Heard of Biomass Transfer and Improved Fallows Rejected the Technologies

Out of 34 farmers indicating they had heard of biomass transfer, 31 tried it on their farms between 1998 and 2004, but a majority later rejected the technology. Three farmers who never tried gave various reasons for not doing so. These were

Fig. 27.1 Proportion of farmers who had practiced either improved tree fallow or biomass transfer technologies



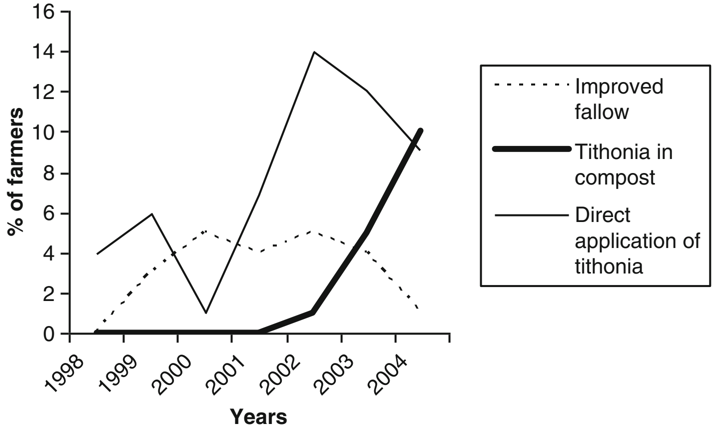


Fig. 27.2 Proportion of farmers using agroforestry based soil fertility technologies in the non-pilot villages from 1998–2004

(i) labour intensiveness, (ii) lack of sufficient knowledge, and (iii) scarcity of plants. A surprisingly high number of farmers who had heard about improved tree fallows never practiced it. During the survey, 43 % of farmers indicated that they had heard of improved fallows, but only a paltry 13 % had ever practised it. Varied reasons were given for the responses: (i) lack of sufficient knowledge, (ii) the small farm sizes, (iii) improved fallow technology does not provide food, and (iv) the technologies did not meet farmers' expectations.

Discussion

The findings of this study have shown that spontaneous diffusion of the technologies did indeed take place, however adoption of both improved tree fallow and biomass transfer technologies was low. This could be attributed to the nature of the two technologies. The main purpose for improved fallow technology is soil fertility improvement, a benefit only achievable in the long term. Farmers in western Kenya are more interested in technologies that give tangible benefits in the short term, i.e., provide food. Because improved tree fallows cannot provide immediate benefits, “they are simply not good enough” in the eyes of the farmers and hence the outcome is the low rate of adoption. Secondly, the technologies are knowledge intensive, and therefore require farmers to understand the technical aspects before implementation. Past research has shown that technologies that are known to have a high rate of diffusion are those that are simple, cheap, and adaptable (IIRR 2000). The findings of this study also show that most farmers who heard about these technologies did not have sufficient information required to implement them. They may not also have observed the associated benefits such as improvement in soil fertility and crop yield. Without this information, farmers seem unwilling to take the risk of investing in a technology about which they had unresolved doubts.

Judging from the 43 % of farmers who had heard about improved tree fallows and 33 % who had heard of biomass transfer technologies, it is possible that some farmers in western Kenya had enough basic knowledge to implement agroforestry technologies, but the context is such that knowledge-based mechanisms never become activated. Most farmers indicated that they had small pieces of land. This and other studies on improved fallows (Keil et al. 2005; Kiptot et al. 2007) have established that farm size influences the adoption of improved fallows. The land availability context was inappropriate for them to make use of the information they had about improved fallow techniques.

Agroforestry technologies involve the planting of a tree component with agricultural crops, and in most cases, e.g., the case of improved tree fallows, farmers have to forego a season’s crop, an option which not many farmers are willing to risk. Agroforestry technologies such as improved tree fallows, in addition to supplying nutrients to crop fields, also provide fuel-wood, and reduce *Striga* (hence less labour is required for weeding). Therefore, when the whole system is looked at in totality, it has been shown to be marginally profitable (Swinkels et al. 1997). Farmers’ number 1 priority is food security and hence an introduction of any system that competes with food crops, such as improved tree fallows, is not an option for farmers where land size is limited and poverty levels very high, unless the system can provide products which put cash in farmers’ pockets to be later converted to food, e.g., sale of tree seeds. Farmers make rational decisions, and therefore when faced with this kind of scenario, the mechanism in play is a kind of cost–benefit calculation (“it is not worth foregoing a season’s crop on a technology that does not provide tangible benefits”). To farmers, implementation is simply not an option, hence their knowledge remains dormant and the outcome is rejection.

One other agroforestry option for soil fertility improvement which can be used without farmers having to plant the trees/shrubs on their farms is biomass transfer technology. However its adoption has also been quite low, especially in Vihiga district. Reasons given included labour intensiveness and scarcity of the shrubs in the vicinity. So here is a scenario where “contextual circumstances” are again simply not conducive to adoption of the technology, as most farmers cannot simply divert scarce labour meant for cropping to the use of biomass transfer nor do they feel able to sacrifice cropping land for trees/shrubs whose benefits are not immediate. This defeats the objective where land is very scarce, although Kiptot (2008) shows that the technology is promising in areas where farmers are able and willing to plant it on farms, have manure scarcity and can afford to hire casual labour. What this means is that the poorest farmers, with the smallest farm sizes, are unlikely to plant biomass banks on-farm as this would take up space meant for agricultural crops. Farmers are therefore being encouraged to plant along contours and terraces.

Participating farmers in pilot sites shared knowledge about agroforestry technologies mainly with their relatives, friends and group members. Relatives proved to be the most important source of information. This is due to the fact that visiting relatives is a common social activity in Kenya, hence the high number of farmers who heard about the technologies from their relatives. Such sharing does not necessarily extend the technologies to farmers who have no close ties with the participating farmers. This may partly explain why a substantial number of farmers had never heard of improved fallows (57 %) and biomass transfer (67 %). The other possibility is that those farmers in non-pilot sites who had never heard of the technologies had friends and relatives in pilot villages who simply rejected the technologies and therefore had nothing to show or tell their kin from non-pilot sites.

Agroforestry technologies are knowledge intensive; they require a lot of understanding before implementation. Informal social networks alone may therefore not be sufficient to enhance adoption, because some farmers with the technologies are unable to explain the principles to other farmers. Some farmers end up testing the technologies without following the right agronomic recommendations, thereby leading to low yields. The state extension system on the other hand is ineffective, and even readily available effective technologies are unable to reach farmers outside the limited number of sites in which researchers are working. This sends a strong message to researchers that the marginal superiority of a complex technology is not good enough. It must either be so superior as to sell itself, or low-cost mechanisms of technology transfer such as using farmer networks must be put in place to ensure that farmers outside pilot areas can access information. But then this raises some questions about whether the social mechanisms of community participation in technology transfer are sufficient. This study has shown that although informal social networks are important sources for enhancing spontaneous diffusion, as shown by Kiptot et al. (2006), Nathaniels (2005), Van Duuren (2003), Simpson and Owens (2002) and van der Mey (1999), they are not on their own fully sufficient to enhance adoption. The social networks need technical support from institutions that have the expertise and extensive grassroots networks.

Conclusions

This study has shown that there was indeed spontaneous diffusion of the two technologies, however adoption was very low. This raises fundamental questions about context and underlying mechanisms for adoption of soil fertility enhancement technologies in western Kenya. To a casual observer, one candidate mechanism could be lack of sufficient technical information due to the inefficient extension service, but it is doubtful whether providing information about the technologies would have made any difference considering that farmers are realists who make rational decisions based on simple cost–benefit analysis. The implication for this is that researchers need to go back to the drawing board to rethink their strategy. But one issue which needs to be given closer attention by researchers is the context under which technologies are developed. What we have seen here is that even if there's spontaneous diffusion, adoption can simply not take place if the context is not right. Finally, spontaneous spread of improved innovations remains a goal for researchers, but basic effort is still needed to come up with low-cost innovative extension approaches that will provide the required technical back up to spontaneous diffusion of innovations.

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Chapter 28
Agricultural Innovations That Increase Productivity and Generates Incomes: Lessons on Identification and Testing Processes in Rwandan Agricultural Innovation Platforms

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Abstract The central question in increasing productivity and generating incomes in African agriculture is how to move from technology generation to innovations that respond to constraints of agricultural production along the value chains. This question was considered in the context of subsistence agriculture, smallholder production systems, inefficient marketing and investments by the private sector, a preponderance of public interventions, and inadequate policies. The Integrated Agricultural Research for Development (IAR4D) presents an opportunity to address the question as it involves innovative principles, demand-driven research, and utilizing organizational

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capacities of multi-stakeholders and relevant agricultural policies. The key element in identification and testing of agricultural innovations in the concept of IAR4D was the establishment of agricultural Innovation Platforms (IPs). IP stakeholders were used to identify and rank constraints to agriculture production along the value chains in their respective sites and contexts. Two to three main constraints were identified and translated into research questions that were envisaged to generate practical solutions for productivity and better marketing strategies while conserving natural resources. The research proposed a package of innovations and each stakeholder was assigned a role in testing, disseminating, and adopting each of them. A research agenda based on beneficiaries' demand, targeting value addition, and income generation was elaborated and implemented. Achievements so far indicate a high efficiency of agricultural innovations collectively identified and participatory methods tested by IP stakeholders, such as potato harvest and postharvest technologies in Gataraga IP and hence validating the efficiency of IAR4D over traditional participatory methods of agricultural research and dissemination.

Keywords Agricultural innovations • IAR4D • Innovation Platform • Innovative technologies • Partners • Productivity • Stakeholders

Introduction

Sub-Saharan African (SSA) agriculture largely remains traditional and is concentrated in the hands of smallholders. Given the dominance of rain-fed agriculture, yields are low. Nevertheless, it remains an important economic sector in Africa. African agriculture contributed 29 % of Gross Domestic Product (GDP) in 1979–1981 and 25 % in 2002–2004 compared with the world averages of 7 % and 3 % respectively (Economic Commission for Africa 2009). The key challenges to agricultural production and farmers' livelihoods improvements include the linear top-down delivery of agricultural research results; the failure for agricultural Research and Development (R&D) to go beyond production and include markets, policy and natural resources management; the poor communication and collaboration between all actors within a commodity value chain from inputs through production, value addition/processing, and marketing to consumption (Stroud 2004). There is also massive undercapitalization of agriculture and research, inadequate use of mechanization and agrochemicals, inadequate investments in irrigation, and low land and labor productivity as well as climate variability (Mekonnen et al. 2009). Small-scale farmers predominate in a situation of increasing population pressure, food insecurity, very low and declining levels of agricultural productivity and rapid natural resource degradation (Beintema and Stads 2004). The poor performance of African agriculture can be attributed not only to inadequate and inappropriate policies but also to institutional bottlenecks. The lack of dynamism of many agricultural markets is an important cause of poor performance of the agriculture sector (de Laiglesia 2006).

Agricultural R&D systems such as Participatory Research and Development (PRD) have been the main channels of building agricultural productivity and food security (Gonsalves et al. 2005). Public research organizations conduct 94 % of agricultural R&D works in most countries in SSA. Many agricultural research organizations have a supply-driven orientation. Their role is technology development prior to "handing over" to dissemination channels with little strategic planning of their research and its potential impacts (Ashley et al. 2009). Although there have been some islands of success, past Agricultural Research and Development (ARD) efforts have failed to fully respond to agriculture challenges due to their linear approach and ignoring the basic needs of the farmers and other interested stakeholders such as input dealers, traders, processors and consumers in ARD process (Scoones 2005). Such an approach to agricultural research is often described as sectoral, linear, and fragmented with little or no involvement of relevant stakeholders (Tenywa et al. 2011a).

The concept of Integrated Agricultural Research for Development (IAR4D) was proposed to bring solutions to the failures of R&D systems (Daane and Booth 2004). The concept proposed operating principles and guidelines for stakeholders with diverse interests to come together to analyze agricultural problems, to develop solutions and to work together towards the fulfillment of common goals (Hawkins et al. 2009). Therefore, the Sub Saharan Challenge Program (SSA-CP) initiated proof of concept research in three widely differing agroecologies in Western, Eastern, and Southern Africa to assess and validate the usefulness of the IAR4D concept in generating deliverable public goods for the end users, its superiority over conventional approaches, and its applicability as a research approach to generate more end-user acceptable technologies (FARA 2004).

The key element that makes the IAR4D principles work is the agricultural Innovation Platform (IP). Tenywa et al. (2011a) defined an IP as a tool for bringing together multiple stakeholders for visioning, planning and implementing or applying of new ideas, practices, and services, which arise through interaction, creativity, insight, and empowerment of the stakeholders to improving the existing situation/conditions around a common interest/challenge and thereby bringing about desired change with a particular interest in farmers' needs, problems and opportunities. In other words, it is a forum for sharing and creating new knowledge and identifying knowledge gaps relevant for planning explicit systemic innovations in agricultural development strategies. This paper presents the process of identification, testing, dissemination and utilization of agricultural innovations and innovative technologies using the IAR4D concept in the Rwandan IPs of the Lake Kivu Pilot Learning Site (LKPLS). Further, the paper presents lessons learnt during the identification and the implementation of activities.

Major Stakeholders and Interfaces in Agricultural Innovation Platforms

The establishment and functioning of an IP are prerequisite environments that are used to identify, test, and utilize innovative technologies while implementing IAR4D. Stakeholders are the backbone of an IP, without them the platform cannot exist nor operate. The choice of stakeholders is driven by their willingness to participate and their potential contribution to move the process towards the achievement of the

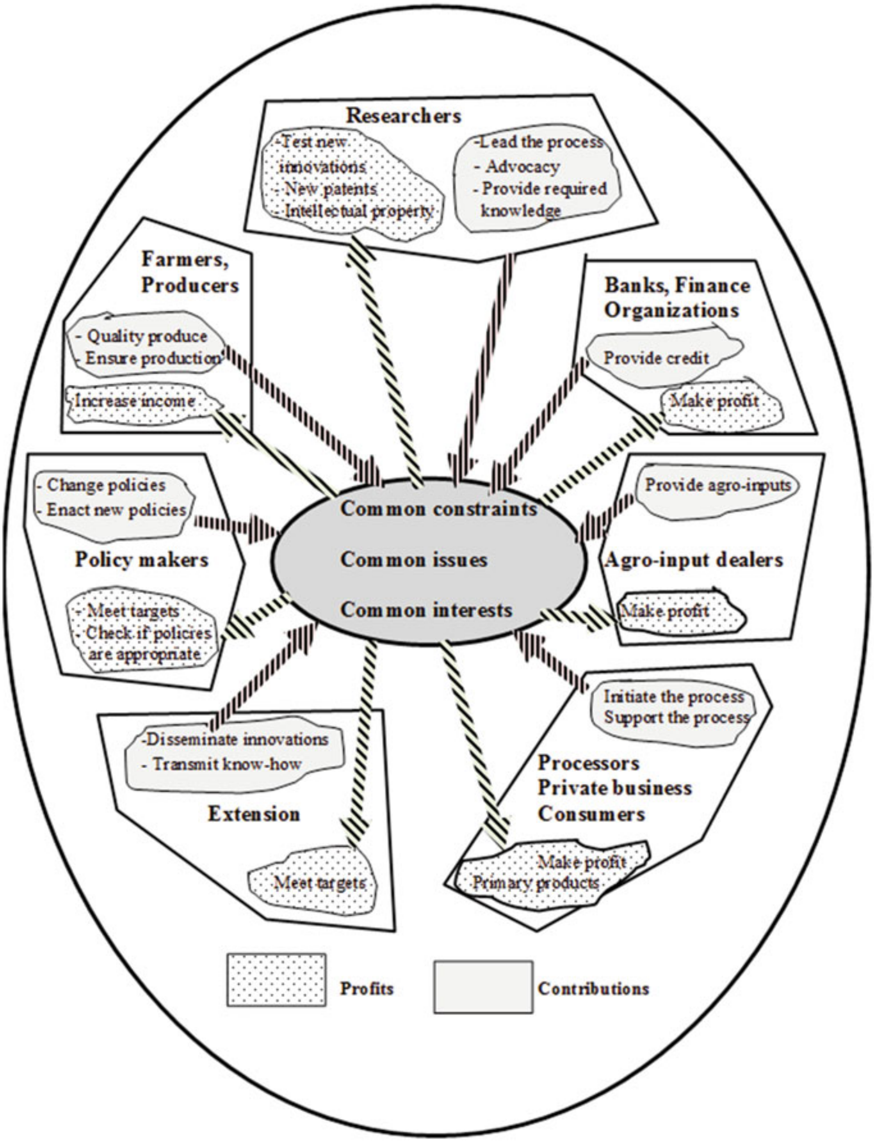

Fig. 28.1 Interfaces in agricultural Innovation Platforms

common interests on the one hand and the foreseen potential benefits they are likely to obtain from the IP on the other hand. Contributions and benefits must be balanced in a win–win scenario to make the IP always attractive and profitable. This is very different from the conventional agricultural R&D approach, which has no strategy nor institutional arrangement that encourages stakeholders to work together.

The potential stakeholders in an IP include farmers and producers, researchers, banks and other financial institutions, agro-input dealers, processors, private business owners and consumers, extension services, and policy makers (Fig. 28.1). Following the principle of contributions versus benefits, researchers may initiate the IP, but more importantly, they provide the necessary innovative technologies and technical knowledge needed to improve the productivity and to make the IP profitable and attractive. The researchers may act as advocates in several instances. The IP constitutes an environment for researchers to test new ideas, and new technologies, and hence have international recognition, intellectual property rights, and patents. Farmers or producers contribute by ensuring the availability of products in the value chains. Farmers gain enormously first and foremost being accepted as equals in the IP with researchers, government officers, traders, bankers, and processors. In the end, they get premium prices on primary products which increase their incomes, food security, and social development and they easily access new technologies.

The IP provides an opportunity to the banks and financial institutions to invest in agricultural value chains where profits are competitive. The banks and financial institutions provide access to credit and finance that are needed to enhance the production for increased profit. The agro-dealers provide agricultural inputs that are in high demand and increase their markets and hence make profits. The processors, private business owners, and consumers are on the top of the value chain and contribute by utilizing IP products and hence act as the driving force of the IP. At the same time they make profits and have reliable supplies of primary products. Extension services help in disseminating innovations and ensuring that new innovations are utilized and in return get recognition. The policy makers enact new, favorable policies, reinforce existing and beneficial policies, and change those that are inefficient, while they have a ground to test the efficacy of enacted policies and hence meet national targets.

Each of the stakeholders is capable of creating an IP based on common issues or while satisfying his/her needs. The processor, private business owners, and consumers can create IPs that supply primary products while banks and financial institutions can form IPs that allow them to invest in the agricultural value chain where they foresee high profits. Policy makers may form IPs to help in validating new policies while researchers create IPs to have testing environments of new technologies and new innovations.

The interactions between IP partners are not linear but are conducted in all directions. The communication and establishment of relationships among partners help move the whole IP system to the common goal. The identification, testing, dissemination and utilization of innovations are done through systems of interfaces where stakeholders contribute, get profits, and interact continually.

Steps in Identification, Evaluation, and Utilization of Agricultural Innovations in Rwandan IPs

The identification, evaluation, and utilization of agricultural innovations were conducted through multi-phased, participatory, action learning approaches. Four important phases were considered: establishment of IPs, planning, implementation,

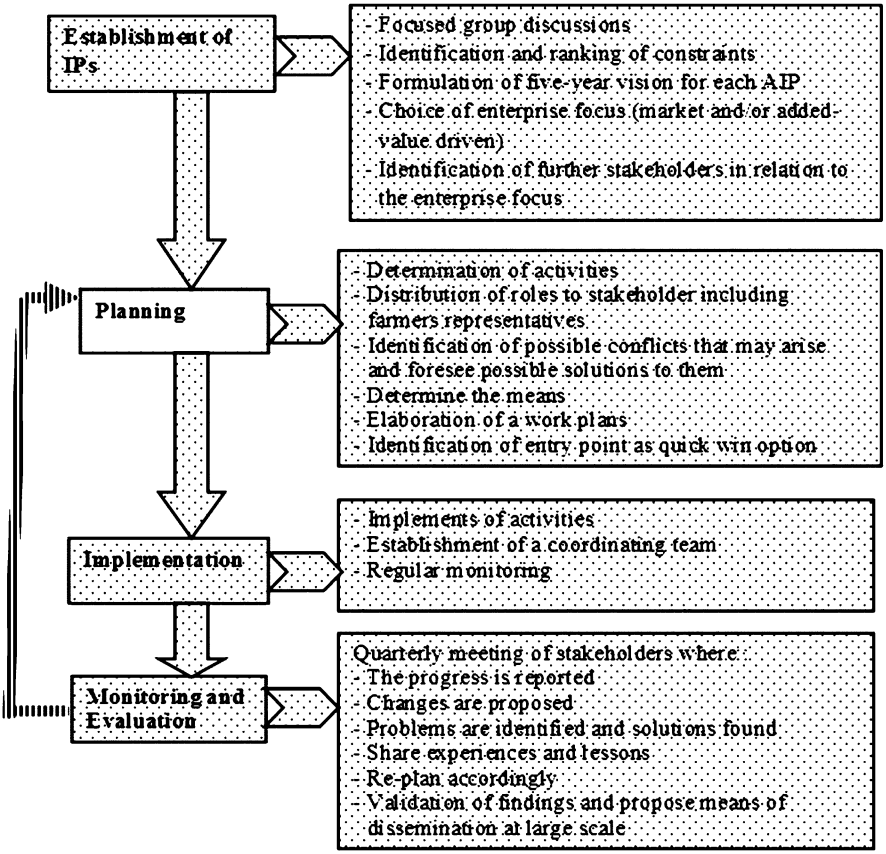

Fig. 28.2 Steps in identification, evaluation and utilization of agricultural innovations in Rwandan IPs

and monitoring and evaluation (Fig. 28.2). The identification was initiated at the establishment of IPs during focused group discussions organized following the procedures of Wong (2008), Powell and Single (1996) and Byers (1991) where potential stakeholders, constraints, and major value chains were identified, and medium-term visions were formulated, thereafter approved during IP establishment meetings.

The defining principles of IAR4D include “perspectives, knowledge and actions of different stakeholders around a common theme and the learning that stakeholders achieve through working together” (Hawkins et al. 2009) so that the process of identification of agricultural innovative technologies started by defining a 5-year vision which was shared by all stakeholders. In all IPs, the vision was about the achievement of food security and income generation (Table 28.1). The agricultural constraints in each IP were ranked using pair-wise comparison methodology (Poursaeed et al. 2010; Saaty 2008; Alphonce 1997) with the participation of all

Table 28.1 Major constraints, enterprise focus, and quick win–win options in Rwandan agricultural Innovation Platforms

Items	Mudende	Rwerere	Gataraga	Remera
Constraints	1. Lack of markets for farm produce especially for milk and potato 2. Insufficient improved varieties of crops and fodder species	1. Insufficient options of sources of income 2. Poor market access, lack of markets	1. Limited markets for farm produces especially for potato and maize 2. Low quality of marketable farm produce 3. Insufficient of improved and marketable varieties	1. Lack and inaccessibility to markets 2. Low quality value of marketable produce 3. Insufficient improved and marketable varieties
Vision	Food security, increased productivity and profits	Food security and enough money to acquire all basic needs	Increased productivity leading to increased incomes and food security	Food security and income to satisfy basic needs
Enterprise focus	Milk/Irish potato	Chili pepper, passion fruit, milk	Irish potato/maize	Bean, maize
Quick-win options	Organize milk market to target Inyange dairy	Introduction of chili and passion fruit cropping to target Urwibutso	Establishing market outlets for potato production, adding value to potato produce	Organize bean and maize markets
Implementing partners	ISAR (presently RAB), CIAT, Imbaraga, NUR, ISAE, MAK, SAC-R	Urwibutso, ISAR (presently RAB), CIAT, Imbaraga, NUR, ISAE, MAK, ANS-R, SAC-R	ISAR (presently RAB), CIAT Urugaga Imbaraga NUR, ISAE, MAK	Urwibutso, ISAR (presently RAB), CIAT, Urugaga Imbaraga, NUR, ISAE, ANS-R, SAC-R
Other partners	Core IP members, BRD, Sector Executive Secretary, Milk collectors	Core IP members, Banque Populaire, Sector Executive Secretary	Core IP members, Input traders, Supermarkets and restaurants, Sector Executive Secretary	Core IP members, Sector Executive Secretary

ANS-R Action Nord Sud-Rwanda, *BRD* Banque Rwandaise de Développement, *CIAT* International Center for Tropical Agriculture, *ISAE* Institut Supérieur de l'Agriculture et de l'Elevage, *ISAR* Institut des Sceiences Agronomiques du Rwanda, *MAK* Makerere University, *NUR* National University of Rwanda, *RAB* Rwanda Agriculture Board, *SAC-R* Send-a-Cow-Rwanda stakeholders. The first three constraints were used to select the enterprises' focus to be used in proofing the effectiveness of IAR4D. The enterprise focus was chosen based on its likelihood to create impact, its socioeconomic importance, its likelihood to involve and bring benefits to all stakeholders and its likelihood of making all stakeholders moving towards the IP vision. It was validated by all stakeholders (Table 28.1).

The planning phase consisted of identification of specific activities and sub-activities to be conducted and allocating them specific partners, including farmers' group representatives, according to their ability and capacity (Tables 28.2 and 28.3). The targets were set, indicators elaborated, and milestones and completion periods agreed. At this stage, other activities not necessarily related to the enterprise focus were identified based on their relevance and included in the plan. The critical stage in planning was the identification of possible conflicts that would likely arise during the implementation and other subsequent phases. It was very important to foresee such conflicts before undertaking activities.

Issues and constraints common to all stakeholders in the IP were clearly articulated enabling each partner to know its exact role and to conduct activities as planned (Tables 28.2 and 28.3). The means for conducting activities were discussed during the planning phase. Each stakeholder brought the means at his/her disposal such as staff and an efficient planning of their utilization was performed by promoting synergy and complementarity. Furthermore, more partners were identified and engaged (Table 28.1). Their choice was on competence in conducting a given activity and on disposal of more means and facilitations highly needed in the value chain. The potential contribution of the new stakeholders was balanced with the potential benefit from IPs.

The last step in the planning phase was the selection of a quick-win option that would allow entering the IP, hence demonstrating the importance of the IAR4D (Table 28.1). The quick-win option was an action that has short-term impact. It was a market of an existing product, an improvement in agronomic practices, and/or an improvement of a step in the value chain. The quick-win options made all partners confidently undertake activities, to reduce fears of risk and be assured of success.

The implementation phase was very crucial because this is where each partner demonstrated their ability to work towards the common goal and showed how synergy and complementary among stakeholders with different origins, disciplines, interests, and capabilities were working. In fact, synergy and complementary of partners with different disciplines and interests but working towards the same goal and interactions among stakeholders in all directions, instead of linear approaches, were the major outputs from the IAR4D approach. Special relationships established among stakeholders were an important advantage and output of IAR4D approaches over the R&D systems. It was observed that stakeholders from various horizons were enthusiastic to work together, to know each other, and to establish particular relationships.

The monitoring and evaluation were conducted at all steps of implementation, but more importantly during the quarterly meetings where each partner submitted a detailed quarterly report of their activities emphasizing success, constraints and

Table 28.2 Progress and achievements in Mudende and Gataraga IPs

IP	Issue	Activity	Progress
Mudende	Linkage of famers to milk markets	Organize milk market to target milk collectors and dairies	The capacity of milk production: 6,000 L/day
			Milk handling procedures are very poor
			Training of 50 milk producers on milk handling
			Linkage of producers to milk collectors at Rubavu, Musanze, and Kigali
			Approximately 3,000 L/day are sold with 50 Frw/L higher than the market price
			Construction and equipment of a collection center financed by BRD (Rwandan Bank of Development)
	Improve cattle feeding	Participatory introduction and evaluation of fodder species	Six fodder species were introduced and participatory evaluated: *Brachiaria molato, B. marando, Chloris gayana, Medicago Sativa, Desmodium incinatum and D. Intoritum*
Gataraga	Organize potato market to target restaurants, hotels and supermarkets in Kigali	Apply harvest and post harvest innovations	All potato growers are using haulm destruction (haulm pulling or haulm cutting),
		Link producers to Kigali market	Washing potato system for supermarkets and scribing for restaurants
			8 t of potato per week are delivered to Kigali supermarkets, hotels and restaurants
			14 supermarkets, hotels and restaurants in Kigali have been linked to Gataraga IP
		Organize maize markets	100 t of maize grain sold to Maizerie de Mukamira at 30 Frw/kg higher than the market price
			10 t of maize grain sold to traders
			18 t of maize seed sold to RADA at a price double than the market price
	Clean potato seed	Clean potato seed and marketable varieties	Three varieties: Kinigi, Mabondo, and Sangema participatory evaluated. Kinigi variety was selected to be used for Kigali market
			The right seed size and spacing have been determined and are used to produce potato for Kigali market
			1,500 t of seed produced using positive and negative selections

Table 28.3 Progress and achievements in Remera and Rwerere IPs

IP	Issue	Activity	Progress
Remera	No organized market for maize and bean produces	Organize bean and maize markets	50 t of maize grain sold to Maizerie de Mukamira 10 t of maize seed sold to RADA 8 t of beans rich in ion and zinc sold to Harvest Plus as seed Collective marketing has been adopted Land consolidation has been strengthened Two varieties of beans (Cansilida and Rucagu) have been highly adopted (almost 100 % adoption)
	Insufficient adapted varieties	Promotion of improved varieties	Four bean varieties were promoted, but only two (Cansilda and Nyiranigisenyi) have been adopted in very short period One variety of maize has been introduced
	Alternative source of income	Alternative source of income	5,000 seedlings of passion fruits have been distributed to 100 farmers, introduction of passion fruit cropping systems
Rwerere	Low farmer income	Chilli production to supply Urwibutso market	Around 2.5 ha cultivated under organic conditions were harvested and sold to Urwibutso Introduction of chili cropping Introduction of organic farming
	Alternative source of income	Participatory introduction of passion fruit crop	3,000 seedlings of passion fruit were distributed to 60 farmers Introduction of passion fruit cropping

possible solutions to them, what worked well and what did not work well, and how to make the process better. It was an occasion to resolve conflicts. Completed activities with practical conclusions were presented. Specifically, practical conclusions and possible utilizations of agricultural innovations that had showed possible impact were proposed. At the same time means of dissemination and dissemination plans were elaborated and implemented. A team in charge of daily coordinating, monitoring, and evaluation of activities was established. This team was required to submit a report to the quarterly meetings.

The quarterly meetings were opportunities to re-plan based on the past experience. New activities, new agricultural innovations, and new actions were added while existing ones were modified or redirected and new partners proposed and engaged in IPs. Furthermore, it was an avenue to find out how partners felt and discuss issues of balancing the contribution and the gain from the IAR4D process. Finally, it was on opportunity to see how to make the approach more profitable to every stakeholder in a sustainable manner.

Progress and Achievements in IPs under IAR4D Systems

Mudende sector had the capacity of producing 6,000 L/day (Table 28.2) of milk before implementation of IAR4D principles through IP systems. However this milk was sold at a very low price to several middle-men and was of bad quality due to inappropriate handling procedures. The quantity sold per day did not exceed 1,000 L/day so much of it was lost. After the IP system was established and the IAR4D concept applied for 2 years, farmers (milk producers) were linked to markets and could sell 3,000 L/day at a higher price (Table 28.2). They were also linked to banks (BRD) and were able to construct a modern milk collector so that the remaining 3,000 L/day were stored and sold later to markets situated as far as Kigali city. Furthermore innovative milk handling techniques and fodder species were introduced and so improved greatly the quality of milk produced while the training on milk handling enabled producers to reach the standards of Inyange Dairy, the major dairy company in Rwanda.

Irish potato in Gataraga sector was the major staple crop and was planted in rotation and/or in intercropping with maize. However, potatoes of several varieties were harvested in bulk, were of poor quality, and were a mixture of all sizes. Both potato and maize were sold to rural assemblers at very low price. There was little interaction between producers and the markets. Stakeholders were moved by the fact of ensuring accessibility to Kigali-City markets composed by supermarkets, hotels, and restaurants. Potato producers were able to access markets in Kigali and hence fetched high prices. Research and extension agencies disseminated new packages of innovative technologies whereas hotels, restaurants, and supermarkets in Kigali obtained high quality potato produce (Nyamulinda et al. 2011). The IAR4D systems introduced changes in cropping systems where potato planting was thoroughly planned to ensure continuous supply of potato produce.

Beans and maize were the staple crops of Remera sector and were planted in rotation. However both bean and maize were used for self-consumption so that most of the harvest was used at home with very little quantity sold in the local markets. With the implementation of an IP system and IAR4D principles, two improved bean varieties were introduced tested, multiplied, and disseminated; collective marketing was promoted, and the land consolidation system was adopted so that producers accessed markets and had enough produce for marketing (Table 28.3). The land consolidation system consists of putting together small household plots to have large areas of at least 5 ha. The consolidated land is planted with one crop and one variety with the utilization of inputs and modern agronomic practices (Kathiresan 2012). Rwerere Sector is situated in a remote area with non-accessibility to Kigali and other markets. However, Urwibutso-Nyirangarama, the major fruit agroprocessor in Rwanda, is easily accessible from Mudende Sector. Therefore, chili pepper and passion fruit were introduced and disseminated while Rwerere IP was linked to Urwibutso-Nyirangarama.

Lessons, Experiences, and Conclusions

Van Asten et al. (2009) distinguished three major constraints associated with R&D such as Farmers Participatory Research (FPR). The first constraint concerned the insufficient insight into systems complexity where farmers and scientists could have insufficient insights into systems complexity like different dimensions and interactions within a system (e.g., farming system, soil–plant–pest interactions). The second constraint was the difference in reference frameworks. Farmers tended to use their farm and immediate surroundings as the reference framework for observations, whereas scientists mostly used universally accepted reference frameworks, measurement units, and classifications. The third constraint was the methodological error where methods used to involve farmers in research could lead to the collection of inaccurate and/or misleading information. Under IAR4D, these constraints are minimized because stakeholders work together around a common theme with interactions in all dimensions, there is integration of analysis, actions, and change across different environmental, social and economic dimensions (Hawkins et al. 2009).

The identification, testing, and utilization of agricultural innovations undertaken following the IAR4D principles resulted in agricultural options that were quickly adopted, applied in a very short period, and profitable to all stakeholders along the value chain (Tables 28.2 and 28.3). The conventional R&D systems have not been able to achieve such results in a very short period because of linear actions where stakeholders on the top of the chain wait for those at the bottom to finish the work and provide the product (Arvidsson and Mannervik 2009). Markets and agroprocessing were the driving forces of the value chain making innovative technologies demand driven whereas in the R&D systems research and extension are the main driving forces and push technologies forward (Stroud 2004).

One very important advantage of IAR4D over traditional systems, demonstrated in this work was the fact that all the partners along the value chain shared a common goal, had a common target, and knew the actions of each other. This is not the case in traditional approaches where research or extension provides ready-made research outputs to the next stakeholder without knowing its goal and objectives (Daane and Booth 2004). The utilization of quick-win options was an important tool to make IP interesting as impact was achieved in a short period, thus allowing activities to be undertaken with confidence.

The partnership, synergy, and complementarity of research with other stakeholders in the IP along the value chains were unique for the IAR4D approach. This was enhanced by the fact that each stakeholder was involved not only for the contribution they were capable of making but also the profit they expected to obtain. The system of balancing profits and contributions made the IP more attractive and more sustainable. Furthermore working together towards a common interest enhanced national policies and built new and strong relationships among stakeholders. The communication was not linear; rather it was done in all directions allowing partners to interact at will during the process (Tenywa et al. 2011b). The work demonstrated that with the IAR4D approach, the partners focused on reducing transaction costs within the value chain, not only in joint activities, but also in core mandates. Success depends on the quality of facilitation and strong market-led and knowledge-based interactions (Tenywa et al. 2011b). The complexity of managing several stakeholders with different backgrounds and interests, and the complexity of interactions between partners and conflicts that may arise between particular stakeholders are seen as major challenges that may lead to failure. Furthermore, the IP involving many partners with different and sometimes opposing backgrounds may be difficult to manage and may involve high costs in terms of financial and human resources. However, the benefits of IAR4D approaches are too important so that the IP seems to be the tool to utilize and hence to move from R&D static approaches to active IAR4D systems. In the considered IPs, new innovative technologies and agricultural innovations that responded to end-user needs were developed and used and this resulted in socioeconomic benefits. Small-scale farmers increased their income and were able to improve their livelihoods by building new houses, paying school fees for their children, and more importantly articulating their agriculture, research, and development demands with research institutions.

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Chapter 29

ISFM Adaptation Trials: Farmer-to Farmer Facilitation, Farmer-Led Data Collection, Technology Learning and Uptake

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Abstract Integrated Soil Fertility Management (ISFM) aims to increase crop yields while conserving natural resources. Participatory research approaches are designed to address challenges in uptake of these knowledge-intensive technologies. ISFM adaptation trials have been developed to evaluate technologies across a wide range of agroecological and socioeconomic environments, while enabling resource-extensive, large-scale participation through farmer-to-farmer facilitation. A study of 144 ISFM adaptation trials in South Kivu, DR Congo was conducted from June to July 2011 and consisted of questionnaire interviews, field evaluation, farmer-collected data analysis, and in-depth interviews. This study aimed to (a) document the farmer-to-farmer facilitation approach, (b) assess the success of farmer-led data collection, and (c) evaluate farmers' learning and subsequent technology uptake. The farmer-to-farmer facilitation system ensured a high percentage of trained assistance to farmers: during trial installation, 87 % of farmers were helped either by farmer technical advisors, facilitators, or agronomists, whereas this percentage was 47–58 % during agronomic operations throughout the season. This facilitation system decreased project costs while increasing participant numbers, thus lifting participatory research above a small scale. The farmer-led data collection was successful in terms of uniform trial establishment

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and yield measurements: 76–90 % of adaptation trials were installed correctly in terms of manure and mineral fertilizer application and crop arrangement. A total of 82–85 % of farmer field books were returned after the growing season, and missing crop yield data was low in 91–93 % of all field books, although this percentage was less favorable for the participatory evaluation section. Farmers' learning was medium to high among 79–89 % farmers with regard to sowing in line, mineral fertilizer application, improved seeds, and crop arrangement. However, technology uptake was more variable, with 53–85 % of farmers partially or fully taking up improved varieties, crop arrangements, and second legume planting, while only 27 % said they continued with mineral fertilizer application. Future research should develop a data quality assessment method of farmer-collected data, which would improve reliable statistical analysis. Further, the effect of intensity and quality of farmer-to-farmer facilitation on data collection and quality and farmers' learning and technology uptake is not yet well understood.

Keywords Integrated Soil Fertility Management (ISFM) • On-farm adaptation trials • DR Congo • Farmer-led data collection • Technology learning and uptake

Introduction

Soil fertility depletion and soil degradation are major biophysical causes of low agricultural productivity levels in sub-Saharan Africa. An African Green Revolution is therefore urgently needed (Sanchez 2010). Integrated Soil Fertility Management (ISFM) aims to increase productivity while conserving natural resources through the use of improved germplasm, judicious mineral fertilizer application, organic matter management, and agronomy adapted to local conditions of smallholder farmers (Vanlauwe et al. 2010). On-farm demonstration trials have shown that ISFM can significantly increase economic benefits in legume cassava intercropping systems in the Central-African highlands as compared to farmers' common practice (Pypers et al. 2011). However, knowledge-intensive practises such as ISFM tend to perform well on research stations but farmer adoption rates remain low, especially in sub-Saharan Africa (Giller et al. 2009). For simple technologies (e.g., high yielding varieties) and homogenous farming environments, conventional research with its top-down, linear technology transfer paradigm might have worked. For knowledge-intensive technologies and complex farming systems, it is increasingly recognized that we need more interactive, experiential approaches taking into account users' experimentation (Röling 1996; Douthwaite et al. 2002).

Participatory research has been proposed to bridge the gap between research and farmers' reality. "Learning by doing" is likely to improve relevance and adoption of technologies (Chambers et al. 1989; Pretty 1995). Biggs (1989) differentiated between four modes of participation, which were further developed by Lilja and Ashby (1999) into a typology of participatory research: (a) Conventional: scientists take decisions alone without communicating with farmers; (b) Consultative: scientists take decisions alone, but engage in organized communication with

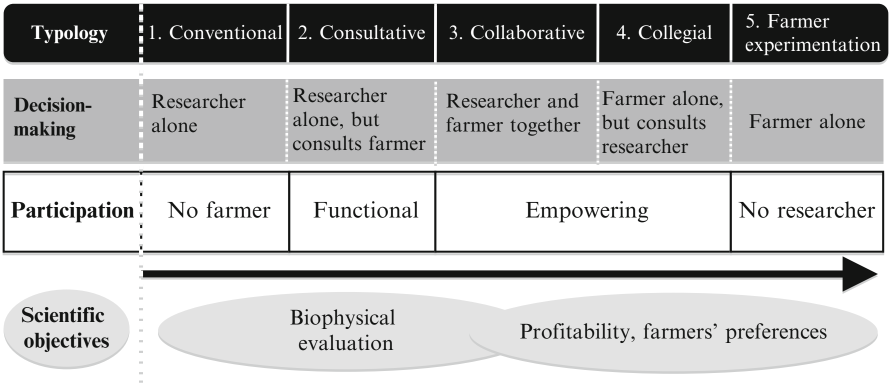

Fig. 29.1 Typology of participatory research (Adapted from Lilja and Ashby (1999) and Franzel and Coe (2002))

farmers. Scientists choose whether or not their decisions are affected by farmers' priorities; (c) Collaborative: decision-making is shared between scientists and farmers through organized two-way communication; (d) Collegial: farmers take decisions alone, but are in organized communication with scientists. Farmers choose whether or not their decisions are affected by scientists' priorities; (e) Farmer experimentation: farmers take decisions individually or in a group, without being involved in organized communication with scientists. If considerable decision-making power is transferred to the farmers (collaborative, collegial, farmer experimentation), the research becomes empowering. These forms of participation could occur in three distinct project phases: Design, testing, and diffusion. Franzel and Coe (2002) add that different participatory trials are suited for different scientific objectives. If researchers' control over the trials is high (conventional, consultative), trials are likely to fulfil conditions of scientific rigor and are therefore well suited for biophysical (statistical) evaluations. Assessments of farmers' preferences and constraints and profitability are more realistic if farmers have high control over trials (collaborative, collegial, farmer experimentation) (Franzel and Coe 2002). Figure 29.1 summarizes these concepts.

The Consortium for Improvement of Agriculture-Based Livelihoods in Central Africa (CIALCA) has been operating in 10 mandate areas in DR Congo, Rwanda, and Burundi since 2005 (CIALCA 2009). CIALCA adapted the Mother and Baby trials (Snapp 2002; Snapp et al. 2002) to develop new participatory on-farm trials, called ISFM demonstration and adaptation trials. The adaptation trials aim to tackle two fundamental criticisms of participatory approaches: Firstly, it is claimed that biophysical evaluation is difficult under farmer management due to uncontrolled factors (Franzel and Coe 2002; Snapp 2002). Secondly, critics argue that participatory research is time and resource intensive so that it can only be conducted on a small scale (Johnson et al. 2003). Table 29.1 summarizes similarities and differences between Mother and Baby and ISFM demonstration and adaptation trials. Both approaches are similar with respect to modes and objectives of the Mother or ISFM demonstration trials. Contrary to baby trials, ISFM adaptation trials aim to collect biophysical performance data, covering a wide range of agroecological

Table 29.1 Comparison between Mother and Baby trials and ISFM demonstration and adaptation trials. Typology is based on the classification of Lilja and Ashby (1999) and scientific objectives on Franzel and Coe (2002). Facilitation refers to assistance during trial setup, management and data collection (Data for Mother-Baby trials is retrieved from Snapp et al. 2002)

		Mother and Baby trials		ISFM demonstration and adaptation trials	
		Mother	Baby	Demonstration	Adaptation
Typology	Design	Consultative	Consultative	Consultative	Collaborative
	Testing	Consultative	Collegial	Collaborative	Collegial
Scientific objectives	Biophysical performance	Yes	No	Yes	Yes
	Profitability	No	Yes	Yes	Yes
	Farmers' preferences	No	Yes	No	Yes
Facilitation	Setup	Researchers	Farmers and enumerators	Researchers	Farmers (assisted by technical advisors)
	Management	Researchers	Farmers	Researchers	Farmers
	Data collection	Researchers	Enumerators	Researchers	Farmers (checked by technical advisors)

and socioeconomic conditions. Participating farmers are trained, install and manage the trial, and collect biophysical data, with assistance from farmer technical advisors, who are elected on the level of farmer associations. This farmer-to-farmer facilitation allows for large-scale participation and data collection, while costs are kept low.

Despite of the considerable interest in participatory research, there are only few studies that document and evaluate the success of participatory on-farm approaches (Snapp 2002). Therefore, this study aims to document the adaptation trials, more specifically:

- Document the farmer-to-farmer facilitation approach.
- Assess farmer-led biophysical data collection.
- Examine farmers' learning and technology uptake.

Materials and Methods

Study Area

The study was conducted in South Kivu, DR Congo, and included all four Action Sites—Burhale, Lurhala, Kabamba, and Luhihi. In the highlands of South Kivu (1,600–2,000 m above sea level), rainfall is bimodal and allows for two growing

Table 29.2 Treatments of adaptation trial packages. Farmers could choose between three different trial packages. Each package comprised three treatments, which illustrated the additive benefits of ISFM technologies. Treatments were laid out in three adjunct plots (6 m × 6 m)

	Package 1		Package 2		Package 3	
	Crop arrangement	Mineral fertilizer	Crop arrangement	Mineral fertilizer	Crop arrangement	Mineral fertilizer
T1	Free	No	Free	No	Free	Yes
T2	1 m × 1 m	No	0.5 m × 2 m	No	1 m × 1 m	Yes
T3	1 m × 1 m	Yes	0.5 m × 2 m	Yes	0.5 m × 2 m	Yes

seasons. The short rains last from February to June (season B), while the long rains stretch from September to January (season A). The area receives a total of 1,500–1,800 mm rainfall per year. Main food crops include cassava, maize, sweetpotatoes, sorghum, bananas, common bean, groundnut, and soybean. Farmers commonly intercrop cassava with legumes without any specific arrangement. Average yields range from 400 to 800 kg/ha for grain crops and 10 to 15 t/ha for cassava fresh tubers. Until recently, the area has mainly been isolated from new research and development projects. Most farmers have very limited access to improved varieties, manure, and mineral fertilizer. Population density is high (300–350 inhabitants per km^2), and average agricultural land size therefore low (0.3–0.4 ha). Soils in Burhale and Lurhala are highly weathered and rather infertile, characterized by a heavy clay texture, low soil pH, and nutrient deficiency. In Kabamba and Luhihi, soils benefited from recent volcanic ash or mudflow deposits, resulting in higher pH and more nutrient content and therefore higher soil fertility (Farrow et al. 2007; CIALCA 2011; Pypers et al. 2011).

Trial Establishment and Management

ISFM adaptation trials commenced in the 2008B/2009A and 2009A/2009B growing seasons. From discussion and evaluation of the ISFM demonstration trials with farmers and NGO partners, best-bet ISFM technologies for cassava intercropping had been identified. Cassava needs two seasons to mature, which allows for two legume intercrops. Farmer organizations within the Action Sites informed their members about the trials and collected names of interested farmers. Participating farmers committed to collect all required data in a field book, and received a trial package with all necessary inputs in return. Farmers could choose among three different packages with three treatments each, which demonstrated the additive effect of ISFM technologies (Table 29.2). Improved germplasm for cassava, soybean, and common bean was used throughout. If available, farmers were asked to apply an equal amount of organic inputs on all three plots. The trials were supposed to be installed on homogenous land (similar land use history, no gradient) as three adjunct 6 m × 6 m plots. The farmers executed all field operations from trial installation to weeding and harvesting.

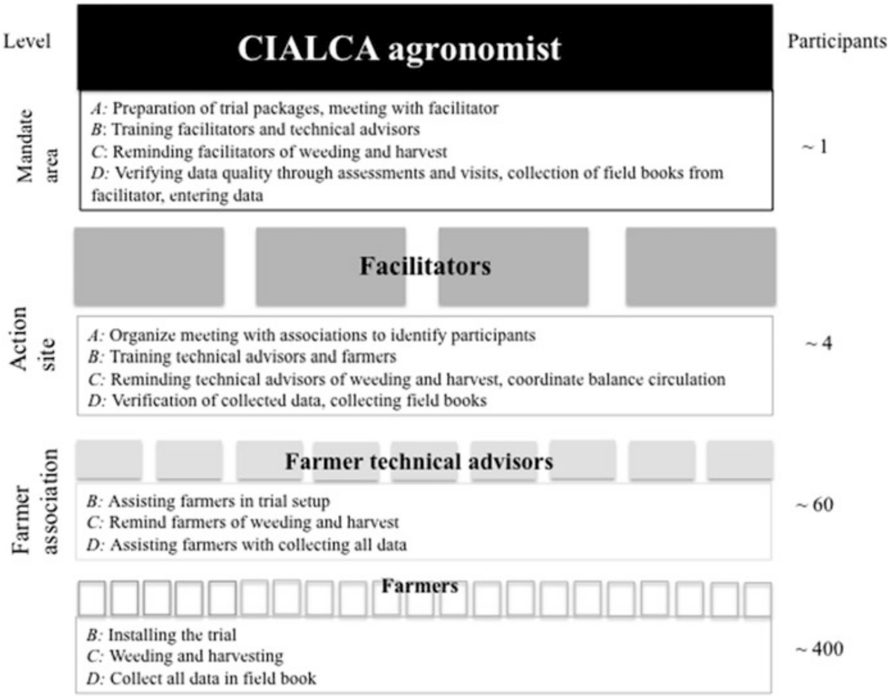

Fig. 29.2 Schematic presentation of farmer-to-farmer facilitation system of the ISFM adaptation trials. The *central column* specifies different actors and assigned roles during key periods. A = before growing season, B = trial installation, C = trial management, D = data collection. The *left column* refers to the level at which the respective actor is operating, and the *right column* specifies the approximate participants per mandate area and season at each level

Farmers were supported in trial installation, management, and data collection by a farmer-to-farmer facilitation system (Fig. 29.2) comprising:

- Farmer technical advisors: the members of participating farmer associations elected three technical advisors, who were supposed to provide close follow-up of 3–10 adaptation trials, and assist in data collection.
- Facilitators: all association members elected one facilitator per action site, who coordinated all activities and constituted the contact point for researchers.
- CIALCA agronomists: composed the packages, trained the facilitator and technical advisor, and reminded them of agronomic activities.

Survey Design

To evaluate the ISFM adaptation trials in the 2008B/2009A and 2009A/2009B seasons, several instruments were combined. A questionnaire survey was conducted in all action sites between 5 and 22 July 2011 among 144 farmers and

36 technical advisors. Using a stratified sampling strategy, we randomly selected 4–6 farmer associations at each action site, 2–3 technical advisors of each selected farmer association, and 2–6 farmers of each selected technical advisor. The questionnaire took around 1 h, included closed and open questions, and addressed farmer learning, technology uptake, and facilitation. A technical evaluation survey verified trial installation and management among all participating farmers. CIALCA students and agronomists visited the farmers' fields between 9 April and 28 April 2008 (2008B/2009A) and 19 November and 28 December 2008 (2009A/2009B). For this study, only data from the same 144 surveyed farmers was analyzed. Field books were collected after the 2009A and 2009B growing seasons, and the total return rate calculated. Different sections of the field books of the 144 surveyed farmers were analyzed. In-depth, semi-structured interviews were undertaken with seven key informants in July 2011, including CIALCA agronomists and facilitators. Questions addressed the level and quality of facilitation, constraints, and ideas for improvement.

Results and Discussion

Farmer-to-Farmer Facilitation System

A survey among ISFM adaptation trial participants revealed assistance by different actors during key field operations (Fig. 29.3). During installation, only 1 % of the participants did not receive any assistance, and in 11 % of the cases only untrained assistance (family members, neighbors). The farmer technical advisors helped 78 % of farmers, whereas the facilitators assisted 8 % and the CIALCA agronomist could only help 1 % of the farmers. The proportion of trained assistance (CIALCA agronomist, facilitator, technical advisor) decreased with subsequent planting and harvest operations. Technical advisors still assisted approximately half of the participating farmers (45–54 %), whereas the facilitator helped 2–4 %. These results show that the farmer-to-farmer system ensures high assistance rates, especially at the time of trial installation. Although farmers are trained in trial setup and management, it can be assumed that a large proportion still needed assistance with understanding and implementing the trial protocol. Further, these results underline that farmer technical advisors are responsible for the major fieldwork. This saves project resources while reaching a maximum number of farmers, although technical advisors should be compensated for their opportunity costs (Fig. 29.3).

Farmer-Led Data Collection

The prerequisite for biophysical data collection is a uniform trial installation. The 144 trials were assessed in terms of homogeneity of the plot, manure

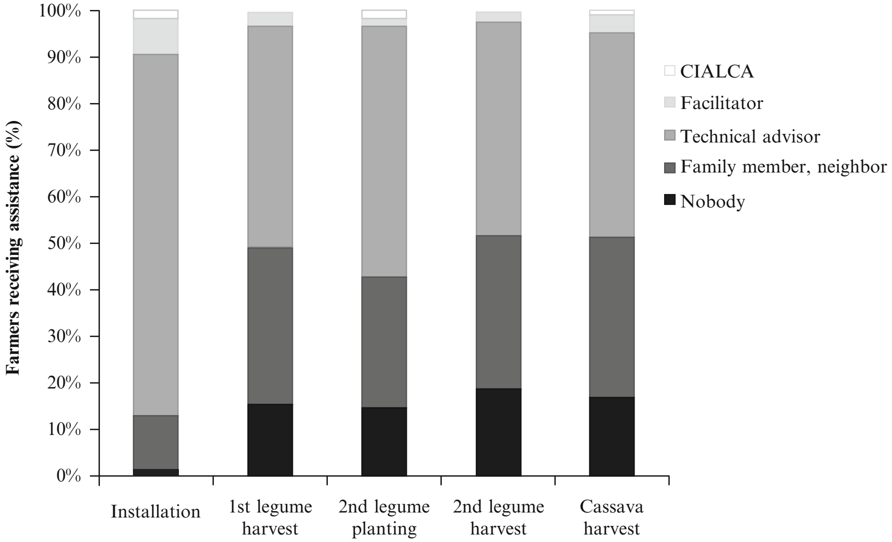

Fig. 29.3 **Farmer-to-farmer facilitation during field operations**. Farmers were asked if somebody assisted them in key field operations (trial installation, harvest of first legume, planting of second legume, harvest of second legume, harvest of cassava), and if yes, who assisted them (CIALCA > facilitator > technical advisor > neighbor/family member). If several actors assisted, the highest level was counted

application, fertilizer application, and crop arrangement (Fig. 29.4a). For the latter three criteria, 76–90 % of the farmers installed the trials correctly. However, only 56 % of participating farmers chose a homogenous plot for their trials. This is the result of high population pressure in the area, which corresponds with scarcity of land. The overall high correct trial installations might be the consequence of the high assistance rates of the technical advisors during trial setup (Fig. 29.4a). Of the 276 (2008B/2009A) and 387 (2209A/2009B) field books that were distributed in all Action Sites in South Kivu, 82 % and 86 %, respectively, were returned after the growing seasons (data not presented). The assessment of a subsample of the 144 field books revealed that missing data differed between field book sections (Fig. 29.4b). Missing data for first legume and cassava yields was low in 91 % and 93 %, respectively, of the assessed field books, whereas the same proportion was

Fig. 29.4 (continued) choice, manure and fertilizer application, and cassava and legume arrangement. Installation was coded as incorrect if plots were situated on a strong slope, if manure was not applied at equal quantities to all plots, if fertilizer was applied to incorrect plots, and if crops were planted without arrangement. (**b**) Missing field book data: values are calculated for different field book sections (household information, field information, first legume management/yield/farmer evaluation, second legume management/yield/farmer evaluation, cassava management/yield/farmer evaluation). Low refers to <10 % missing data, medium to 10–50 % missing data, and high to >50 % missing data

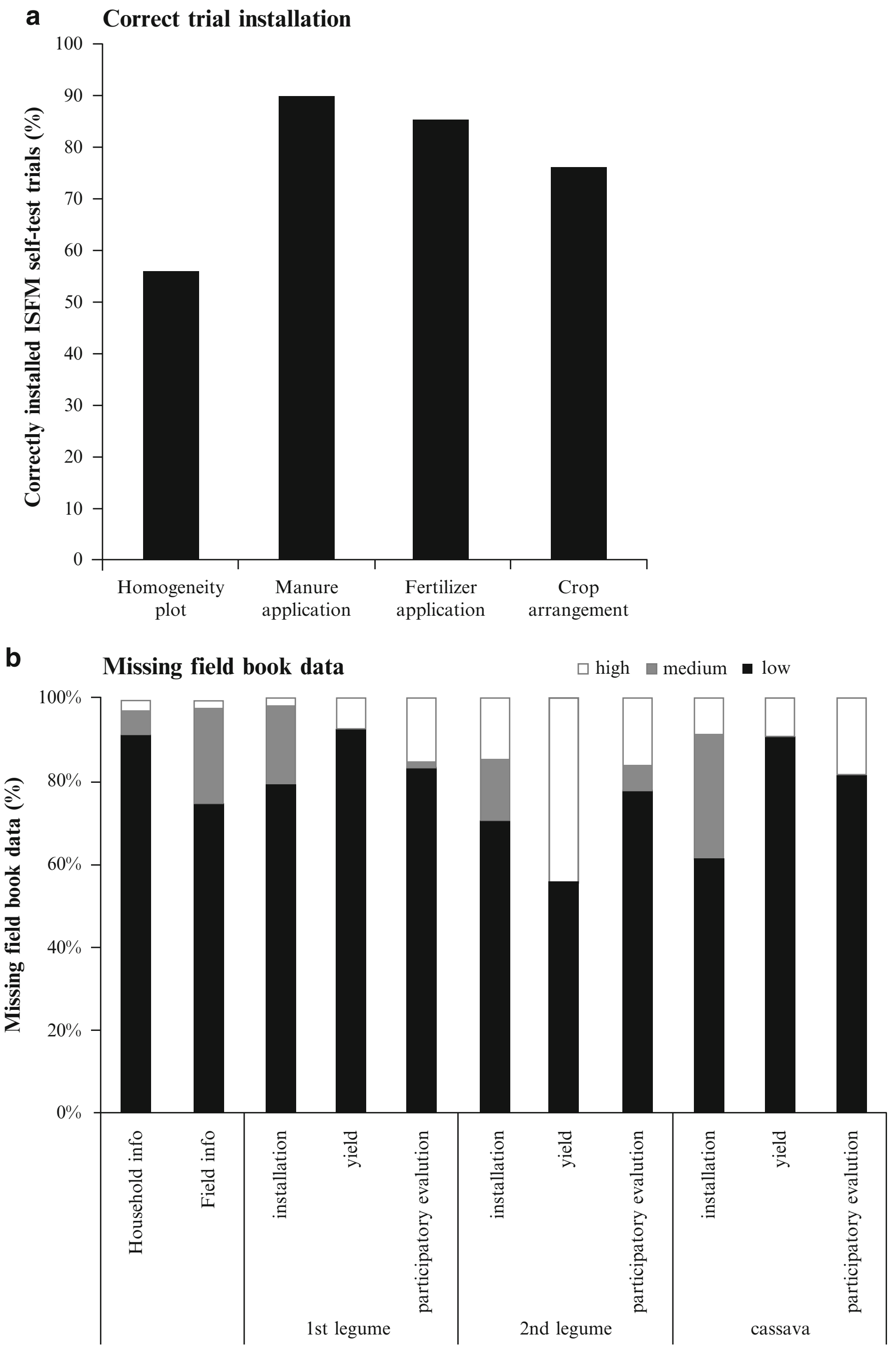

Fig. 29.4 Farmer-led data collection of adaptation trials. (a) Correct trial installation: proportion (%) of farmers who have respected the trial protocol concerning homogenous plot

only 54 % in case of the second legume. Many farmers did not plant or harvest the second legume because they perceived shading from the growing cassava plants too excessive for second legume growth. The percentage of missing data was higher for the participatory evaluations (15–19 %) than for yield data (7–9 % when not considering the second legume). The participatory scoring of technologies according to pre- and self-defined criteria appeared to be more difficult to understand for both participating farmers and technical advisors than biophysical data collection.

Farmers' Learning and Local Technology Dissemination

Farmers assessed their own learning experiences with ISFM technologies (Fig. 29.5a). Regarding sowing in line, mineral fertilizer application, utilization of improved seeds, and crop arrangement, 79–89 % of the farmers rated their learning medium to high. This percentage is lower for second legume planting (50 %) due to reasons discussed in the previous paragraph. High learning is especially prevalent for improved seeds (46 %) (Fig. 29.5a). When looking at uptake of the same ISFM technologies, the variance between technologies was higher than within the learning experiences (Fig. 29.5b). Between 53 and 85 % of all respondents said that they (partially) took up sowing in line, utilization of improved seeds, crop arrangement, and second legume planting. This proportion was considerably lower for mineral fertilizer application (27 %). Most farmers expressed resource constraints and lack of market access as major hurdles to fertilizer use. In general, uptake was lower than learning about the technologies. Farmer experimentation (farmers take research decisions only under consultation with researchers) could further empower farmers, and researchers could better learn more about farmers' constraints in using mineral fertilizer (Fig. 29.5b).

Conclusions

The ISFM self-test trials seemed successful in terms of data collection (correct trial installations, return of field books, completeness of data) and farmers' learning, although technology uptake seemed to be low. Farmer experimentation would shift more decision-making power from researchers to farmers, which could enable researchers to better understand farmers' constraints and preferences. The farmer-to-farmer facilitation is an integral part of the self-test trials, ensuring participating farmers receive assistance in correct trial installation and harvest. This facilitation decreases project costs while increasing participant numbers, thus lifting participatory research above the small scale. Socially just compensation schemes for technical advisors are crucial to justify their high workload. Future research should further examine the quality of the data collected in field books.

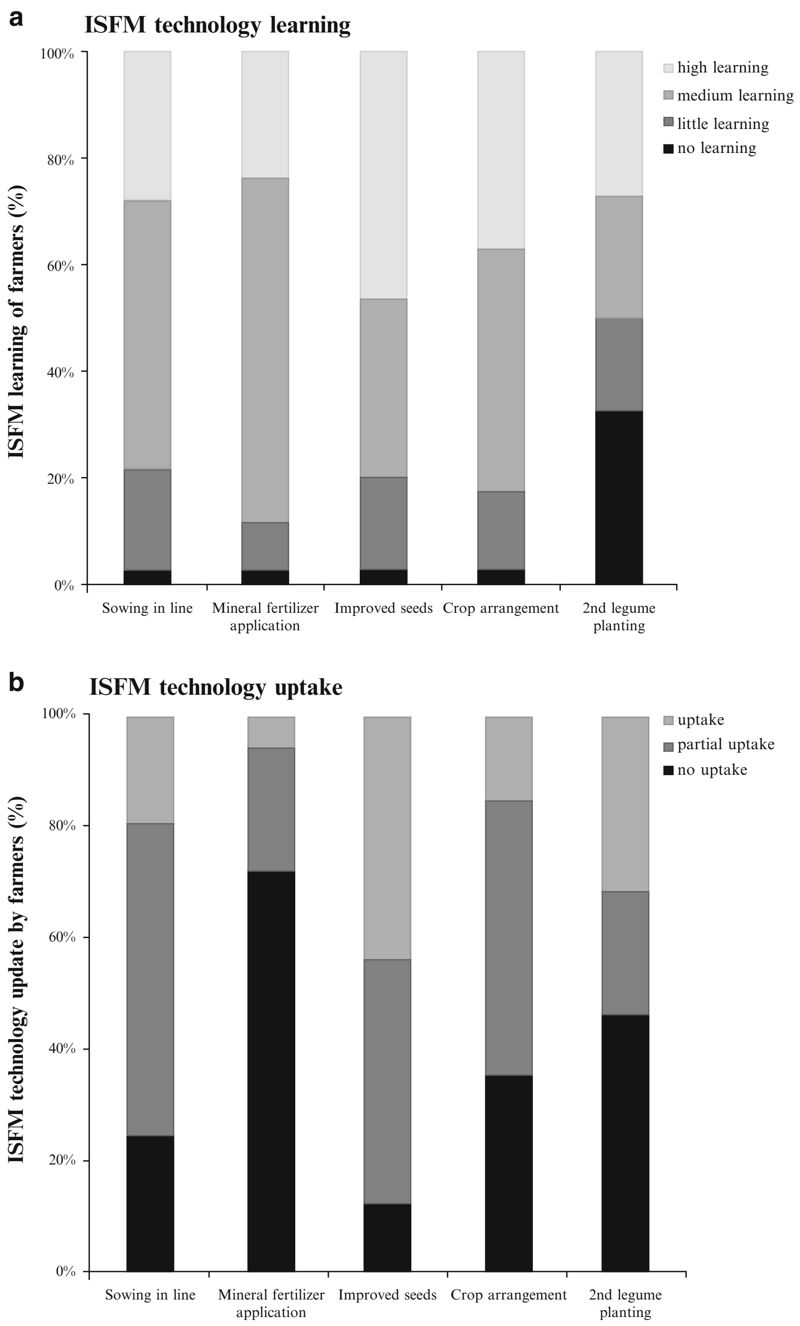

Fig. 29.5 ISFM technology learning and uptake. (**a**) ISFM technology learning: respondents classified their knowledge on ISFM technologies (fertilizer application, improved germplasm, crop arrangement, second legume planting) before and after their adaptation trial on a scale from 1 to 4. The differences between both scores (before and after) were classified as no learning (0), low learning (1), medium learning (2), and high learning (3). (**b**) ISFM technology uptake: respondents were asked if they adopted ISFM technologies (sowing in line, fertilizer application, improved germplasm, crop arrangement, second legume planting), and if yes on parts or all of their field(s)

A verification method needs to be developed that would improve reliable data collection and statistical analysis of farmer-collected data. Further, the effect of intensity and quality of farmer-to-farmer facilitation on data collection and quality and farmers' learning and technology uptake is not yet well understood.

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