Mohamed Behnassi · Shabbir A. Shahid
Joyce D'Silva *Editors*

Sustainable Agricultural Development

Recent Approaches in Resources Management and Environmentally-Balanced Production Enhancement

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Preface

This volume is the outcome of an International Conference held in Agadir (Morocco) in November 2009 titled "The Integration of Sustainable Agriculture, Rural Development, and Ecosystems in the Context of Climate Change, the Energy Crisis and Food Insecurity", chaired by Dr. Mohamed Behnassi. The Conference was jointly organized by the Faculty of Law, Economics and Social Sciences of Ibn Zhor University of Agadir, the North South Center for Social Sciences (NRCS), with the fruitful support and sponsorship of the German Technical Cooperation (GTZ).

This conference was held at a time when world leaders were preparing to meet in Copenhagen on 7–18 December 2009 to negotiate a binding agreement for reduction of green house gases (GHG) to tackle global warming beyond 2012 and to discuss international concerns regarding climate change, energy crises, and global hunger challenges. It is generally understood that if urgent actions are not taken, the ultimate impact of climate change will be the rise of global temperature, change in frequency and patterns of rainfall leading to food insecurity in many developing countries, especially those depending on dryland farming in Africa.

The main objective of the conference was to bring together educators, scientists, researchers, managers, and policy makers from around the world to discuss various aspects of the conference themes and to develop a consensus surrounding the conference synthesis report which contains a set of valuable recommendations, as a way forward for addressing climate change and food security issues.

The conference organizers had received an overwhelming response to the call for papers. The submitted abstracts were reviewed and those deemed appropriate to conference themes were accepted. That led to submission of full papers for conference books. Papers related to conference themes were presented in five plenary sessions and fourteen panels. A natural consequence of the diversity of the papers presented at the conference was the arrangement of the contributions into three books covering different areas of interest. These books can be treated almost independently, although considerable commonalities exist among them. Prior to publication, all pre-selected chapters have been rigorously peer-reviewed by relevant experts.

The papers contained in this book "*Sustainable agricultural development—Recent approaches in resources management and environmentally-balanced produc-*

tion enhancement" represent one part of the conference proceedings. The other part is embodied in separate books which are being published simultaneously. The other books are respectively entitled: (1) "*Global food insecurity—Rethinking agricultural and rural development paradigm and policy*"; and (2) *Climate change, energy crisis and food insecurity: the world in quest of a sustainable face*.

In this book, papers pertaining to sustainable agricultural development are presented in four parts divided into 20 chapters. Part I deals with the sustainable use of land resources as a potential for sustainable agricultural development, including aspects like land resources governance, land grabbing, and implications for food security, turning adversity into an advantage, reforestation and zoo-ecological remediation of soil quality improvement, mitigation of salinization, and policy frameworks for farmland use. Part II goes on to discuss sustainable management of water resources at farm level, rice fields, reduction of water losses, and extension and education. Part III deals with innovations in agricultural production including slow release nitrogen fertilizers, organic fertilizers, use of waste as a resource, and the implications of animal breeding technologies. Innovative processes in livestock production have been discussed in Part IV focusing on animal husbandry and the use of sorghum, cactus, and halophytes as animal feed. The editors and the publisher are not responsible for any statement made or opinions expressed by the authors in this publication.

We wish to take this opportunity to express our sincere appreciation to the members of the Scientific Advisory Board, and the Steering Committee, chairmen and rapporteurs of the technical sessions and cooperating organizations for hosting the Agadir Conference and for the publication of the books. Special thanks are due to all authors, coauthors, and reviewers without whom this comprehensive book would not have been produced. We also owe our gratitude to all of those individuals and numerous other people who in one way or the other contributed to the conference and the book, especially those involved from Springer publishing.

Finally, it is hoped that this book will be of interest to researchers, experts, and policy makers in the fields of agriculture, soil and water management and conservation, plant production, soil remediation, livestock development, land governance, and environmental protection. Graduate students and those wishing to conduct research in these topics will find the book a valuable resource.

The Editors

Acknowledgements

I have been privileged to share the responsibility of editing this Book (one of the three books based on the best Agadir 2009 Conference Proceedings) with two other participants in the above cited conference: Dr. Shabbir A. Shahid (Senior Scientist, International Center for Biosaline Agriculture-ICBA, Dubai, UAE) and Joyce D'Silva (Compassion in World Farming, UK) whose expertise, commitment, intellectual generosity and insight greatly speeded up the process, and certainly improved the final version of the book manuscript.

On behalf of my coeditors, I would like to gratefully and sincerely thank the members of the Scientific Committee who have actively taken part in the peer-review of the submitted chapters. Deepest thanks and appreciation go to Dr. Sidney Draggan (Environmental Information Coalition, National Council for Science and the Environment, USA), Dr. Nira Ramachandran (Earth Care Foundation, India), Dr. Phillip Bennion (Home Grown Cereals Authority-HGCA, UK), Dr. Sanni Yaya (Ottawa University, Canada), Dr. Jennifer L. Lanier (World Society for the Protection of Animals, UK), Dr. Ingrid Hartmann (Humboldt-University of Berlin, Department of Gender Studies, Agricultural Faculty, Germany), Dr. Marie Bonnin (Institute for Research and Development-IRD, France), Dr. Samira Omar Asem (Food Resources and Marine Sciences Division, Kuwait Institute for Scientific Research, Kuwait), Dr. Ghazi Abu Rumman (ICT International Pty Ltd, Australia), and Dr. Gerald K. Sims (Agriculture Research Service, United States Department of Agriculture, USA).

While the real value of this volume should be credited to the authors of the chapters, whose papers have been accepted for publication after the rigorous peer-review, any shortcomings or errors are undoubtedly the editors' responsibility.

M. Behnassi

About the Editor

The North-South Research Center for Social Sciences (NRCS) is a research organism founded by a group of researchers and experts from both Northern and Southern countries as an independent institution, with no political or state affiliation. Based in Morocco, NRCS aims to develop research and expertise in many social sciences areas with global and local relevance from a North-South perspective and within a complex and interdisciplinary approach. As a think tank, NRCS aspires to serve as a reference locally and globally through rigorous research and active engagement with the policy community and decision-making processes. The Center is currently chaired by Mohamed BEHNASSI, Dr. Prof. in Global Sustainability Politics.

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Abbreviations

ABAD	Agency for Barani Area Development
ABG	Average Body Weight Gains
ACIAR	Australian Center for International Agricultural Research
ADB	Asian Development Bank
ADG	Average Daily Gain
ADOD	Dioctadecyldimethyl Ammonium
AFESD	Arab Fund for Economic and Social Development
AGRA	Alliance for a Green Revolution in Africa
AOAC	Association of Official Analytical Chemists
ARD	Animal Resources Department
ATP	Adenosine-Triphosphate
BIC	Bank Information Center
BW	Body Weight
CAC	Central Asia and the Caucasus
CF	Crude Fiber
CIRAD	Centre de coopération internationale en recherche agronomique pour le Développement
CP	Crude Protein
CPI	Crude Protein Intake
CPL	Global Initiative on Commercial Pressures on Land
CRD	Completely Randomized Design
CSIR	Council for Scientific and Industrial Research
CSIRO	Australia's Commonwealth Scientific and Industrial Research Organization
DEWA	Dubai Electricity and Water Authority
DMI	Dry Matter Intake
DNDC	DeNitrification-DeComposition
DPRN	Development Policy Review Network
EAD	Environment Agency—Abu Dhabi
ÉARFÜ	North-Great Plain Regional Development Agency
EC	Electrical Conductivity
EFSA	European Food Safety Authority

EGE	European Group on Ethics in Science and New Technologies to the European Commission
EU	European Union
FAO	United Nation Food and Agriculture Organization
FIAN	Foodfirst Information and Action Network
FIAS	Foreign Investment Advisory Service
GARB	Genuine Agrarian Reform Bill
GCC	Gulf Cooperation Council
GDP	Gross Domestic Product
GFRP	Global Food Crisis Response Program
GHG	Green House Gases
GLM	General Linear Models
GMO	Genetically Modified Organisms
GTZ	German Technical Cooperation
HCSO	Hungarian Central Statistical Office
HDMA	Hexadecyltrimethyl Ammonium
IAASTD	International Assessment of Agricultural Knowledge, Science, and Technology for Development
ICARDA	International Center for Agricultural Research in the Dry Areas
ICBA	International Center for Biosaline Agriculture
IDB	Islamic Development Bank
IDP	Integrated Development Plans
IDPs	Internally Displaced Persons
IDS	Institute of Development Studies
IFAD	International Fund for Agricultural Development
IFC	International Financial Corporation
IFDC	International Fertilizer and Development Center
IFIs	International Financial Institutions
IIED	International Institute for Environment and Development
ILC	International Land Coalition
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
IRD	Institute for Research and Development
IWMI	International Water Management Institute
MDGs	Millennium Development Goals
MENA	Middle East and North Africa
NARS	National Agricultural Research Systems
NFE	Nitrogen Free Extract
NKTH	National Office for Research and Technology
NRCS	North South Center for Social Sciences
OAE	Office of Agricultural Economics
OECD	Organization for Economic Co-operation and Development
OFID	OPEC Fund for International Development
PAEC	Pakistan Atomic Energy Commission
ROS	Reactive Oxygen Species

RUAF	Resource Centre on Urban Agriculture and Food Security
SCAHAW	Scientific Committee on Animal Health and Animal Welfare
SDF	Spatial Development Framework
SDS	Sudden Death Syndrome
SOFA	State of Food and Agriculture
SWOT	Strengths Weaknesses Opportunities Threats
TNCs	Transnational Corporations
TPS	Town Planning Schemes
UAE	United Arab Emirates
UK	United Kingdom
UNCTAD	United Nations Conference on Trade and Development
UNPD	United Nation Development Programme
USDA	United States Department of Agriculture
UTBS	Urea Treated Barley Straw
UTSS	Urea Treated Sorghum Stover
WANA	West Asia and North Africa
WBG	World Bank Group

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About the Authors

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Clara Ceppa During the last few years, Dr. Clara Ceppa has focused her attention on the current and increasing problem of waste that derives from different productive processes; actually, we know the typology of waste but not the intrinsic potentialities and the new fields of application. Her research has allowed the identification not only of new areas of application of output, as input for other productive processes, but also to determine with precision and localize by territory the flows of material within a complex local network in a well-defined territorial context. The research is distinguished by the realization of a software that can process the acquired data and create new relations and connections between different productive activities to favor a sustainable development of local resources and waste. She is also researching on food-packaging and eco-friendly packaging in order to generate new productive activities and a new open production system in the packaging field.

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Part I
Sustainable Use of Land Resources as a Potential for Sustainable Agricultural Development

Chapter 1
Land Resource Governance from a Sustainability and Rural Development Perspective

Mohamed Behnassi and Sanni Yaya

Abstract This paper reviews the key issues with regard to land resource governance and its dimensions in terms of sustainability and rural development. It explains the links between these areas and the related research and policy implications. It concludes by recommending the required priority actions at the global and country level to move the land resource governance agenda forward within the perspective of promoting sustainability and development of the rural areas and communities. The paper presumes that the land resource governance is expected to remain a key area of national and international engagement in the near future, especially in the context of climate change and food crisis, because the access to land is becoming ever more relevant for livelihood enhancement, food security, and rural development. Moreover, the poor land governance and policies that undermine tenure security often tend to diminish investments and encourage unsustainable practices of land management that generate short-term gains at the cost of social and environmental balance. Based on this, pro-poor, democratic and sustainable governance solutions are urgently required that respect and strengthen the tenure rights and security for smallholder farmers, pastoralists, forest dependent people and indigenous people.

Keywords Land • Pro-poor governance • Tenure security • Land grabbing • Sustainability • Rural development

1.1 Introduction

Considered separately, the financial, food, fuel and climate crises are serious issues. In combination, their impact could be catastrophic for the global economy. Currently, the world is facing many complex challenges including adaptation to

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and mitigation of climate change; rapid urbanization; increased demand for natural resources; growing human food, water and energy insecurity; increased natural disasters; and the resolution of violent conflicts. Many of these challenges have a clear land dimension: unequal access to land; insecurity of tenure; unsustainable land use; and weak institutions for land administration, and dispute and conflict resolution. Responding to these challenges is particularly difficult since land resource governance is weak (Borras and Franco 2008; Palmer et al. 2009). Significantly, land is the single greatest resource in most countries, and land-based resources are natural capital at the disposal of societies—acting as a central ingredient in development choices. Also, it is a basic factor of economic production as well as a basis for social, cultural and religious values and practices.

Land is fundamental to the lives of poor rural people since it is a source of food, shelter, income, and social equity. Therefore, secure access to land reduces vulnerability to hunger and poverty and helps in promoting human development. Moreover, the ways in which this resource is managed—including the rules that govern who gets to use which land resources under which conditions—is central to development outcomes in many societies. This is mainly true where financial capital is scarce, meaning that people's welfare is more directly reliant on the management of natural capital (Platteau et al. 2001). For many of the world's extremely poor rural people[1] in developing countries, however, secure access is becoming more tenuous than ever (IFAD 2010).

Lack of access to natural capital not only constrains development opportunities at the level of the individual, it has macro-economic effects at the national scale as well. This is particularly true with regard to the land resource as there is a confirmed and strong correlation between equity of land ownership for a baseline date and subsequent national economic growth rates. Hence, good governance of land-based resources means positive outcomes of land and related policy in terms of equity, efficiency and environmental sustainability. It is not surprising that land-use planning is becoming a necessity to assess and to identify best available options—at various scales and in the short- and long-term, taking into account the range of stakeholders and social, economic, and ecological trade-offs and externalities (Comby and Renard 1996; Brown et al. 2007).

There is a growing awareness that *pro-poor* land governance is crucial to addressing rural poverty, environmental degradation, climate change, and the exclusion of the poor from legal protections. An inclusive, participatory governance system entails policies to enhance secure access to land[2] and equitable access to mar-

[1] According to IFAD (2010), there are more than 1.4 billion extremely poor people in the world, struggling to survive on less than US$ 1.25 a day, 70% of them live in the rural areas of the developing countries.

[2] Land *access* is broader than land *rights* in a legalistic sense. Land rights do determine access, not only rights of full ownership but also a much wider range of entitlements (e.g., various types of use rights). But access to land is also shaped by social relations, including control over markets, capital, and technology; by relations of power, authority, and social identity; and by relations of reciprocity, kinship, and friendship. These factors may entail a disconnection between having a legal *right* to use land and being *able* to claim and enjoy that right in practice (Ribot and Peluso 2003).

kets and services, especially for smallholder farmers in the developing countries. The ultimate objective of these policies is to enable small farmers to increase production and to reap economic benefits from non-volatile food prices. Also, secure land tenure[3] should prevent looming expropriation and forced migration. It should also stop restrictions which may result from enclosure of land increasingly valuable for conservation, biofuel production, mechanised farming, and urban/industrial or touristic zoning purposes. Although the need for tenure security is not new, the urgency of the issue has perhaps never been greater, especially in the context of poverty alleviation policies and the expectations of the Millennium Development Goals (MDGs).

Competition for land has never been greater. Pressure on land is increasing as a result of the rising world population, climate change, declining soil fertility, and the need for global food and fuel security[4]. Therefore, and because of rapidly growing land demands in a globalizing world of international players, land resource governance is likely to become a key area of national and international engagement in the near future. In the context of climate change and the food crisis, access to land is becoming ever more relevant for sustainable livelihood enhancement, food security[5], rural development, and even international power and influence. Poor land governance and policies that undermine tenure security—such as periodic land redistribution as used in some countries—often tend to diminish investments and encourage unsustainable practices of land management that generate short-term gains at the cost of environmental health (Norfolk 2004). In this regard, pro-poor, democratic, and sustainable governance solutions are urgently required (Bruce and Migot-Adholla 1994; Bertrand 2000; UNPD 2009). These solutions surely respect and strengthen the tenure rights and security of smallholder farmers, pastoralists, forest dependent people and indigenous people.

This chapter reviews key issues related to land resource governance and its dimensions in terms of sustainability and rural development. The chapter explains the links between these areas and related policy implications. It concludes by recommending priority actions needed at global and at country level to move the land resource governance agenda forward within the perspective of promoting sustainability and development of the rural areas and people—especially in a context marked by many challenges such as biodiversity degradation, climate change, and water, energy and food shortage (Le Bris et al. 1982; Le Bris et al. 1991).

[3] *Land tenure* pertains to all rules, norms and institutions that govern access to land.

[4] With countries and businesses now recognizing the potential of growing some fuel crops on land that cannot sustain food crops, even less-fertile land may now have value (IFAD 2010).

[5] During the current food crisis, most statements of concern and proposed solutions in the international summits—addressing how to achieve increased food security for more than one billion undernourished people—have not focused on the deeper form of insecurity related to the crisis that is also on the rise: insecurity in access to land for more than 1.5 billion people in smallholder households involved in agriculture.

1.2 Land Resource Governance: Dimensions and Importance

It is increasingly recognized that land is a critical governance issue. Arguably, sound land governance is a crucial key to achieving sustainability and to supporting the global development agenda. Yet, while both *land* and *governance* are familiar terms, their combination as *land governance* is more recent. Moreover, currently the world is facing many complex challenges that have a clear land dimension: unequal access to land; insecurity of tenure; unsustainable land use; and weak institutions for dispute and conflict resolution (Cotula et al. 2009).

1.2.1 Land Resource Governance—A Practical Definition

Land is defined so as to include the Earth's surface as well as its various resources, including water, forests, and fisheries. Also oil, natural gas, and minerals are usually included as land-related natural resources. Land, therefore, is taken to include the physical land (farmland, wetland, pastures, and forests) as well as related natural resources. According to Palmer et al. (2009), five important characteristics of land are useful to recall when developing a definition of land governance: land is more than just an asset; multiple rights to the same parcel of land can be held by different people or groups; land rights, restrictions, and responsibilities are expressed through a socially constructed system of land tenure; land rights can have different sources of legitimacy; and the tenure system is itself an institution with its own institutional framework.

Governance is the exercise of political, economic, and administrative authority in the management of a country's affairs at all levels. It is a neutral concept comprising the complex mechanisms, processes, and institutions through which citizens and groups articulate their interests, exercise their legal rights and obligations, and mediate their differences. According to Palmer et al. (2009), while the term *land* has a long-established history, the concept of *governance* emerged in its current form only recently. As many actors have developed their own definitions, four specific characteristics of the concept are now generally accepted: governance is conceptually broader than government; it emphasizes processes and institutions; with its emphasis on authority, governance recognizes the importance of politics and power; and it is conceptually neutral. Governance refers to the manner in which power is exercised by governments in managing a country's social, economic, and spatial resources (Deininger 2003; Daley and Hobley 2005).

Land resource governance, by extension, concerns the rules, processes, and structures through which decisions are made about the use of and control over land, the manner in which these decisions are implemented and enforced, and the ways competing interests in land are managed. It encompasses statutory, customary, and religious institutions. It includes such state structures as land agencies, courts, and ministries responsible for land, as well as such non-statutory actors as traditional bodies and informal agents. It covers both the legal and policy framework for land as well as traditional and informal practices that enjoy social legitimacy (Palmer et al. 2009). Land governance is about the policies, processes, and institutions by which land, property, and natural resources are managed. This includes decisions on access to land, land rights, land use, and land development. Land governance is basically about determining and implementing sustainable land policies and establishing a strong relationship between people and land (Du Plessis and Leckie 2006; FAO 2007).

Fundamentally, land governance is about power and the political economy of land. The power structure of society is reflected in the rules of land tenure, and the quality of governance can also affect the distribution of power in society. Meantime, weak land governance is a cause of many tenure-related problems, and attempts to address tenure problems are affected by the quality of land governance. By contrast, improving land tenure arrangements often means improving land governance. As well, good governance of tenure can ensure that rights in land and natural resource are recognized and protected. By doing so, it can also contribute to the achievement of a variety of development objectives, including such MDGs as the eradication of extreme poverty and hunger, the promotion of gender equality and the empowerment of women, the enhancement of environmental sustainability, and progress towards a global partnership for development (Lavigne Delville et al. 2001; Lavigne Delville 2006).

Many countries around the world have recognized the underlying link between improved land governance, poverty reduction and the achievement of the MDGs. However, while notable accomplishments have been made, much of the emphasis to date has been on technical improvements of systems and procedures. This is due to the fact that the achievement of good land governance is not easy. Policy reforms to strengthen governance require the political will to overcome opposition and resistance from those who usually benefit from non-transparent decision-making and corruption. Improving governance demands the strong commitment of the people involved, and the capacity development in order to make changes achievable (Fernandes 2006; Palmer et al. 2009).

1.2.2 Dimensions and Characteristics of Land Resource Governance

Land resource governance has social, economic, and environmental dimensions that are interlinked and, therefore, require careful considerations of all available options to minimize potential conflict amongst people and across economic activities (see Fig. 1.1). Given that many developing countries' land is critical to agriculture, mining, wildlife conservation, urbanization, and infrastructural development, governance issues and policies are complex, often requiring juggling acts to balance and satisfy competing interests. Land-use management, therefore, has implications at disparate levels from household to community, from community to national, from sub-regional to regional, and finally to international (Ojalammi 2006; IFAD 2007).

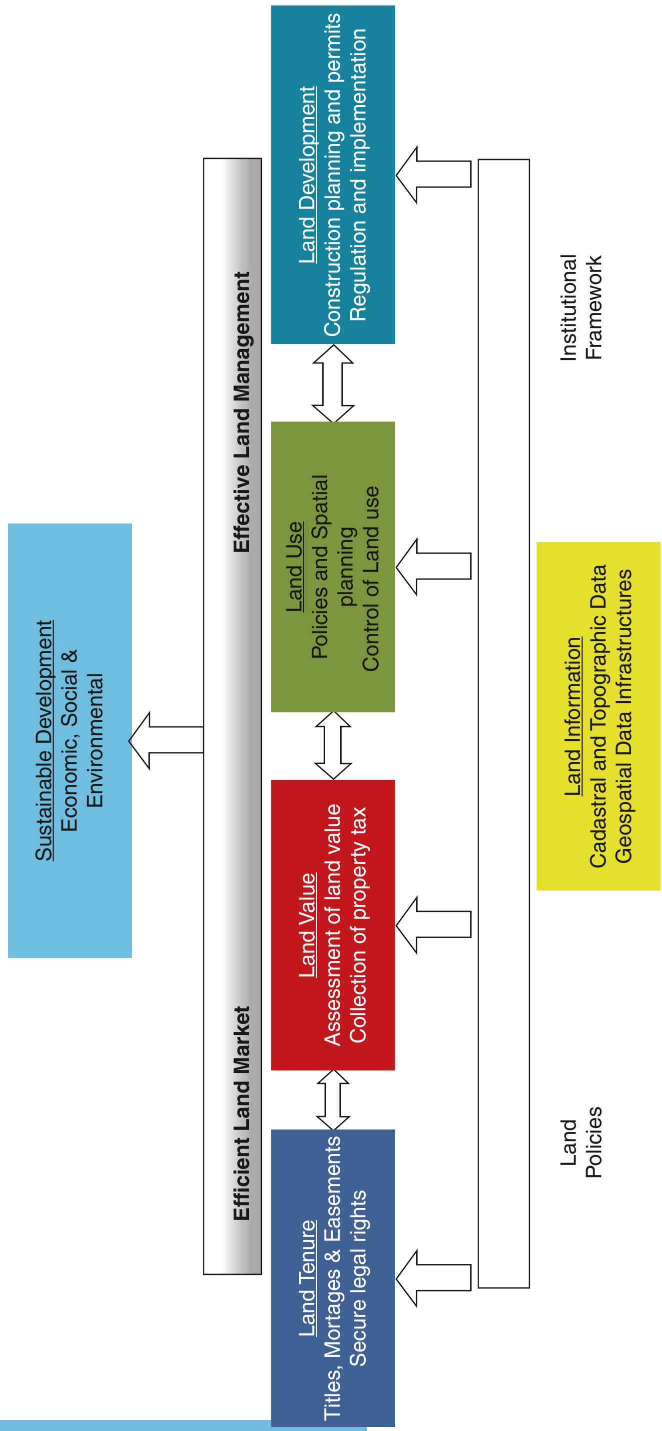

Fig. 1.1 A global land management perspective. (Source: Enemark 2004)

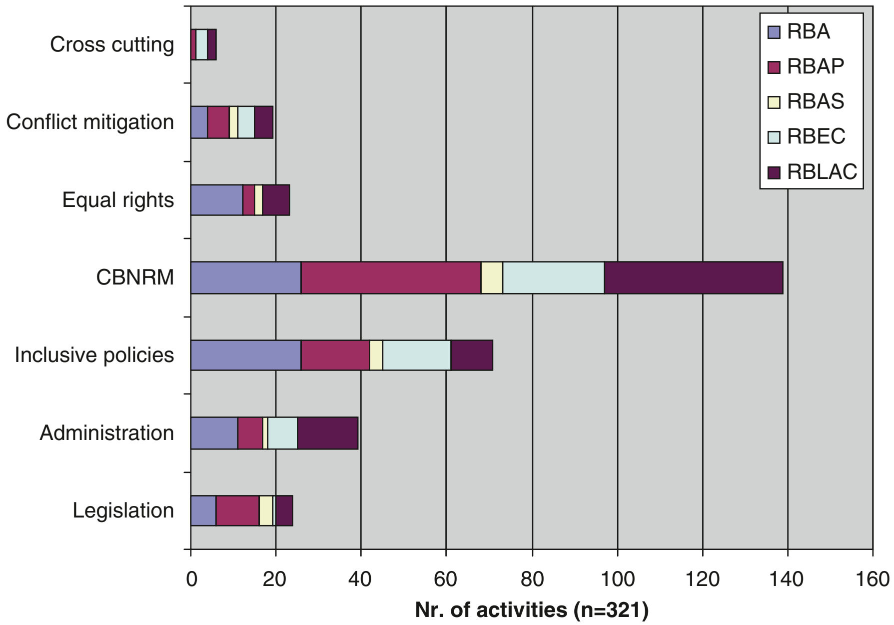

Fig. 1.2 Governance dimensions addressed in current land related project activities in 5 UNDP regions. (Source: Ruben de Koning, Facilitating national processes of governance assessment; posted at: http://www.landcoalition.org)

In addition, when insufficient attention is paid to land access and tenure issues, development projects can become a part of the problem. For example, when irrigation is introduced into previously rain-fed farmland or roads to link farmers to markets, the new economic potential of the land makes it more attractive, and small-scale producers can lose their land to more affluent or powerful settlers (IFAD 2010).

Given these facts, conventional technical approaches to land will not be adequate to address these issues (see Fig. 1.2). One of the reasons is that existing land administration tools are not able to cope with even current challenges. According to Palmer et al. (2009), while reliable statistics are difficult to obtain, there is wide consensus that the majority of people in the world do not have legally recognized and documented rights to land, and that the land rights of most women are weak in quantity and quality. The other reason is that the nature of the problems is simply too complex for traditional linear analysis and sectoral approach. Issues like climate change, informal settlements, and food insecurity are highly resistant to resolution (Quan and Dyer 2008).

Moreover, and even in terms of such standard indicators as corruption, land has long been known to be one of the sectors most affected by bad governance, something that is not difficult to understand given that land is not only a major asset but also that its values are likely to rise rapidly in many contexts of urbanization and economic development. The most authoritative survey of global corruption finds that, except for the police and the courts, land services are the most corrupt sector (Transparency International 2009). Although individual amounts may be small, such petty corruption can add up to large sums—in India the bribes paid annually by users of land administration services are estimated to be US$ 700 million (Transparency International India 2005), equivalent to three-quarters of India's total public spending on science, technology, and environment. Large-scale and serious corruption associated with acquisition and disposal of public lands is more notorious in some contexts. For example, in Kenya "land grabbing" by public officials reached systemic proportions during 1980–2005 and was identified as "one of the most pronounced manifestations of corruption and moral decadence in our society" (Government of Kenya 2004). For private land, bad governance manifests itself in the difficulty of accessing land administration institutions to obtain land ownership information or to transfer property. Together, large- and small-scale corruption will reduce the perceived integrity and, because of high transaction costs, the completeness of land registries; thereby undermining the very essence of land administration systems (Deininger and Enemark 2010).

Therefore, and according to Palmer et al. (2009), the reform *process* is as important as its *content*. Many excellent land policies, laws, and technical reforms have been developed, yet, in many cases, implementation has slipped, stalled, or has even been reversed. Thus, the understanding of land issues and the reform process from a governance, sustainability, and rural development perspective offers insights that cannot only improve the design of reforms, but also offers tools to support implementation. Moreover, it is increasingly recognized that land issues cannot be arbitrarily separated into rural or urban sectors—such distinctions create artificial boundaries that can impede a more holistic approach to the concept and issues of land resource governance.

Moreover, and because governance entails social and economic dimensions, inequitable gender relations often place women at a disadvantage when dealing with land issues (UNEP 2007). Poverty in many developing countries has strong gender dimensions, and women often enjoy weaker land (sometimes they have only user not ownership rights) and natural resources rights than men, which, coupled with inequitable education, lessens the opportunities available to them. In many instances, women are particularly vulnerable because their land rights are often obtained through relationships with men. If the male link is severed, women can lose those rights (IFAD 2010). Albeit more progressive gender-neutral land regulations have recently been enacted in many developing countries (Cotula 2006), these new rules are often implemented in gendered contexts that continue to deny women equal access to land. This is compounded by women's lack of awareness of the statuary laws (Kameri-Mbote 2006). Such a baseline situation shows the existing fragility of women's land tenure security.

Property rights are also at the core of available opportunities. Existing property regimes often favour the rich and other established sectors. This has been particularly evident in land and natural resource tenure. The enforcement of property rights, without due consideration of equity and justice issues, may exacerbate conflict among users at different levels including the local and national, and possibly beyond those. It has been argued that land ownership makes poor people less reliant on wage labour and increases opportunities available to them, thus reducing their vulnerability to crises. Providing poor people with access to land, together with building their capacity to effectively use it, is central to reducing poverty. Also, it empowers the poor and vulnerable communities. Improving land productivity needs to be part of a multi-pronged economic strategy that amongst other things promotes industrial development and diversifies options. Thus, effective land-use management, which takes into account equity and access issues and tenure rights, is critical to sustainable development in many developing countries. Ineffective land-use planning and management can only lead to overexploitation of the resource, contributing to increased land degradation, salinization, pollution, soil erosion and conversion of fragile lands (Shipton and Goheen 1992).

The lack of a clear focus on access to land in many international high-level conferences dealing with such issues as food insecurity, climate change, and sustainable agriculture is a significant gap for two reasons. Firstly, being a primary asset in production, land and natural resources form an essential safety net from food shortage in the poorest households. Being a basis for social relations, access to land is also an important factor in preventing social exclusion, and thus economic exclusion. Secondly, the three key issues that are increasingly evoked (the increase in food and commodity prices, the adaptation and mitigation measures to climate change, and the rapidly increasing use of agro-fuels) are converging factors that are likely to *increase exclusion from land* for the poorest land-users (Cotula 2007). These trends are driving a growing commercial demand for land. Increasingly, this is bringing large-scale investors in land, agricultural production, and potential carbon sequestration in direct competition with smallholders and common-property users for the land these latter use.[6] Because many users have no formal tenure rights on their land, they are vulnerable to dispossession. As documented, for example, in a report entitled *Fuelling exclusion? The biofuels boom and poor people's access to land* (Cotula et al. 2008) released by the FAO and the International Institute for Environment and Development (IIED), dispossession is already evident.

A disparate body of legal and institutional frameworks exists at national, subregional, regional, and international levels to deal with the different dimensions of land. For instance, many resource-rich countries in Africa face special governance challenges related to weak and poorly enforced law and policy. Countries dependent on oil, gas, and mining and those having weak political institutions often have higher levels of inequality and poverty than non-oil and non-mineral economies at similar income levels. Often such countries lag behind in overall development, with higher levels of child undernourishment, lower educational outcomes, and even shorter life expectancy. To maximize the benefits of increased economic growth, countries must build stronger governance structures and strengthen accountability and transparency as well as eliminating graft.

[6] The Tanzanian government, like many African countries, is currently committed to fast-tracking agrofuel initiatives, and switching over vast areas of land to sugar cane, palm oil, and jatropha. The most fertile lands, with best access to water are being targeted, even though these lands are already used for food production by small-scale farmers (African Biodiversity Network 2007).

In terms of agriculture, ministries or departments of agriculture administer different laws and policies aimed at enhancing food production for national consumption as well as for export. The fact that food production in Africa has been declining over the past few decades is arguably an indicator of inefficiency, although there are other root causes. Also, the region has ratified various multilateral environmental agreements, whose objectives vary from biodiversity and biotechnology, climate change and desertification to persistent organic pollutants and other chemicals initiatives. Several of these are directly relevant to the challenges of land. In concrete terms, these international engagements are not fully echoed in domestic policy and law regimes.

1.3 Land Governance: A Reform Agenda

Land governance issues are challenging and reforms to improve this kind of governance are often complex and controversial. While there is a considerable body of experience with policy, legal, and technical reforms in the land sector, not all the experiences are relevant: the political nature of land makes reforms difficult to implement at the elected scale. Meantime, as Palmer et al. (2009) have specified, while the governance dimension of land is increasingly recognized, very few case studies have been prepared explicitly from a governance perspective. Most of the real experience in this area is captured only in the internal documents of development organizations (that is, the so-called grey literature), or often more simply as tacit knowledge in the heads of practitioners. The pressures of the reform process and the sensitivity of the information mean that the experience is rarely captured in real time, or even after. Therefore, the documentation of issues and reform processes should be promoted so that other experiences can inform the debate.

Land governance reforms can cover several important land issues. Yet, given the space limits of this paper, focus will be made on some significant ones:

National land policy formulation National land policy formulation is currently the most fundamental level of decision-making with respect to land. In this sense, it represents the ultimate land governance process where all the major issues should be discussed and debated, including access to land, tenure security, control of natural resources, women's land rights, institutional roles and responsibilities, and resolution of disputes. Every stakeholder should be involved in the identification of issues and potential solutions. The outcomes of this process should involve far reaching impacts on *who* can use the land, how and for *what* development objectives.

It should be recognized that many countries do not have a comprehensive land policy; rather, they have different policies for different types of land and other natural resources: urban, agriculture, forestry, and water. Our aim behind this analysis is to focus on national land policy processes in order to highlight the governance and sustainability dimensions that can be found in any decision-making process related to land and, in this way, have broader relevance to the debate.

Critical questions related to this debate include: who designs and leads the process; how the agenda is set and by whom; who decides who can participate in the process; how the specific views of women and vulnerable groups are incorporated; who is able to influence the debate and how; whose interests are advanced; who may perceive the interests at risk; when is the process "complete"; and how grievances are addressed.

Land Reforms The lesson of land reforms is that there is no short cut. To be done well, land reforms require time and financial resources to build widespread national consensus on, and support for, the reforms, to prepare the needed policies and legislation; to identify and select beneficiaries; to enable the beneficiaries to acquire land under secure tenure condition and develop their farming operations; and to establish conflict resolution mechanisms. Also, time and resources are needed to remove the distortions that provide incentives for large landowners to hold on to land and which encourage beneficiaries to later sell the land they receive. If land reforms are rushed and under-resourced, they will be chaotic, incomplete, and ineffective: large landowners may obstruct the reform process or use their power to capture the benefits, and if targeted beneficiaries actually receive land, there will be a strong chance that they will be forced to abandon it because they cannot make a living.

Because large-scale land reforms are lengthy processes, it is possible for them to be derailed because of changes in government and in the balance of power in society, the emergence of other competing priorities for resources, and the economic downturns. Sustained pressure from social movements and government leaders are needed to ensure that land reform remains on the country's agenda, that adequate funding continues to be allocated to the reforms, and that approaches are continually reviewed and revised in order to overcome problems that emerge during implementation.

Combating the Phenomenon of Land Grabbing In the current context, a global process is underway whereby powerful foreign public or private corporations, investment banks, and hedge funds sign agreements with domestic states. These agreements involve taking possession of or controlling millions of hectare of land—that are relevant for current and future food security of the host country—in Africa, Asia, and Latin America to produce food or biofuels (see Fig. 1.3). Over the past two years, this process has been increasingly researched[7], debated in international seminars[8],

[7] Important studies are the International Land Coalition (ILC), Global Initiative on Commercial Pressures on Land (CPL), and the Dutch IS Academy on Land Governance. For documents on the ILC Global Initiative studies see http://www.landcoalition.org/cplblog/?cat=149.

[8] Significant seminars that were organized on the topic were the 3D Seminar "Land Grab: a Human Rights Approach" held in Geneva 16 May 2009, see http://www.3dthree.org/en/page.php?IDcat=-19&IDpage=51; and the Development Policy Review Network (DPRN) Expert Seminar "Commercial Pressures on Land" held in Utrecht on 8 July 2009. An international academic workshop on "Global Land Grabbing" will be held on 6–8 April 2011 at the Institute of Development Studies (IDS), University of Sussex, Brighton, UK.

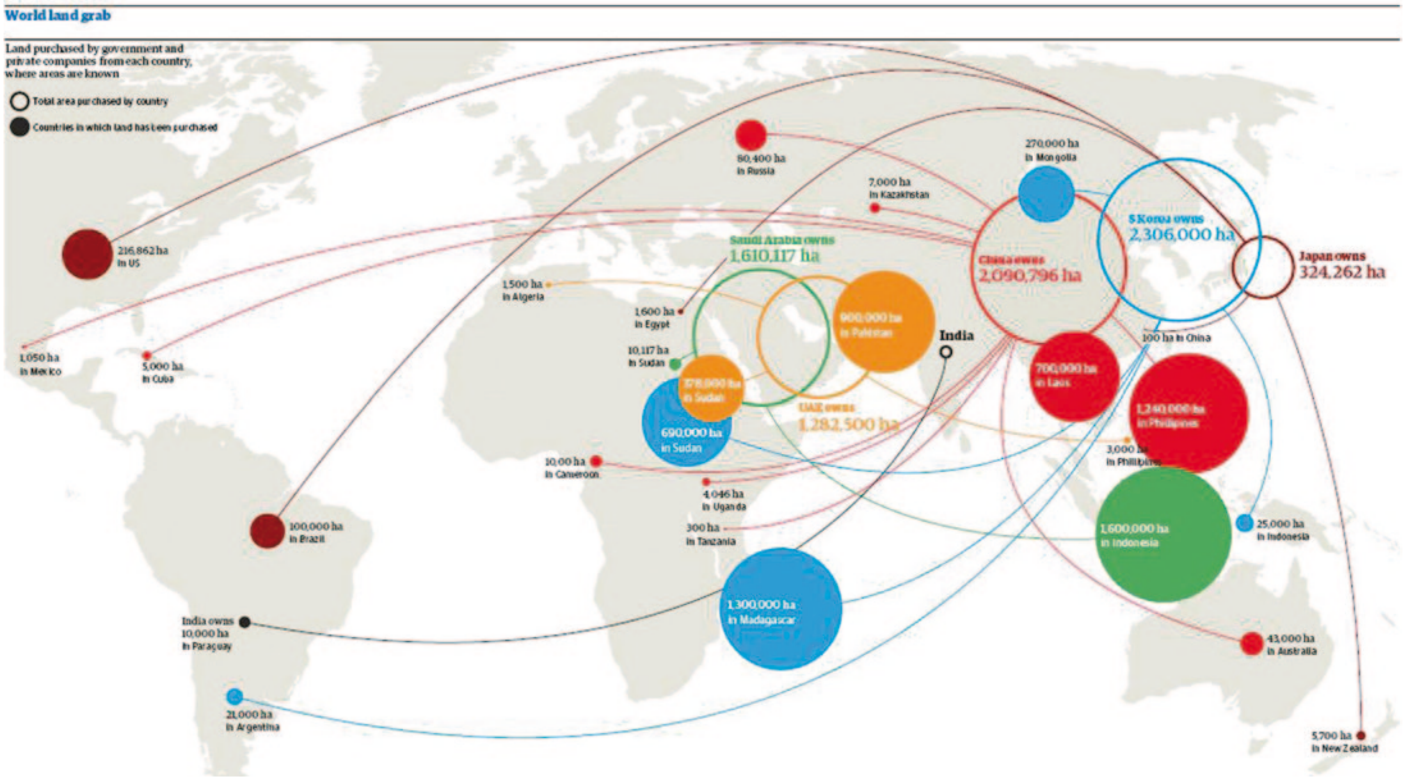

Fig. 1.3 Land deals in the world. (Source: International Land Coalition 2009; http://www.landcoalition.org/)

and described by the media[9] as a growing trend across the world, most notably in Africa (FIAN 2010, p. 8). This trend offers developing countries an opportunity to attract foreign investment, but it brings a potential threat to the land rights of small-scale producers and indigenous communities. Even when the lands taken over are classified as communal, idle, or marginal, they may provide a vital base for the livelihoods of poor people, especially women, who may use the land for crop farming, herding, or collecting fuel wood and medicinal plants (IFAD 2010).

Due to the financial crisis and the boom in agrofuels, food and agricultural products—the main reasons behind the recent surge in land grabbing—access to land as a key part of the right to food (emphasizing thus the right to feed oneself) is increasingly undermined. To be sure, and after three decades of neglect of agriculture, there has been a resurgence, particularly of business interests, in agricultural production. According to one estimate (Don 2008), at least 515 million ha of new land will be required by 2030 to meet the demands of new agricultural production (200 million ha), agro-fuel (290 million ha), and industrial forestry (25 million ha). This does not include demands from shifting production as a result of climate change. The same study estimates that 250–300 million ha of underutilized agricultural land is available that could be put into production. Despite the unwelcome possibility of encroachment into forested areas, and the optimistic possibilities of innovation to significantly increase agricultural productivity, it appears unavoidable that competition for existing agricultural land will increase sharply. Transnational investment in agricultural land—increasingly negotiated on a bilateral basis between governments—is already becoming more apparent. This competition takes place on an uneven playing field—in many cases between large-scale investors[10] and local land-users who often hold no statutory rights over the land they use and need to live on.

According to a report published recently by the FoodFirst Information and Action Network (FIAN),

> over the past years vast tracks of agricultural lands have been taken over by foreign firms. The total area probably surpasses the farmland of France. Much of this land is located in African countries with fast increasing populations suffering hunger and under-nourishment. Such land acquisition has been happening outside public scrutiny and many details are still hidden. This land grabbing has sparked debates in the media, in developmental institutions, in UN organizations and in civil society.

These trends show how peasant farming and pastoralism got increasingly marginalized as a matter of international and national policies. An increasing number of

[9] Grain has kept an inventory of media releases on land grabs which date back to 2002 (and a lost article from 1989). This inventory today counts a total of 1187 articles. A spur in new coverage is found in May 2008. The peak is noticed from April 2009, and still lasts today. See www.farmlandgrab.org. Under a relatively narrower definition, the International Land Coalition has started an inventory in 2009, in which today some 387 articles are kept. For more information: http://www.landcoalition.org/cpl-blog/?cat=149.

[10] Investors include the private sector (banks, agribusiness, investment companies, institutional investors, trading companies, mining companies), and in some cases governments (directly or indirectly), through sovereign funds, domestic investors.

farmers and peasants are now faced with losses of lands to an extent reminiscent of colonial times (FIAN 2010, p. 6).

In a broad sense, land grabbing is not a new phenomenon. It has, unfortunately, been a recurrent pattern in human history. There were many cases in which land grabbers were local and national elites (for example, land lords, paramilitary groups, plantations, and companies) as well as the government itself. The first cases of foreign land grabbing related to mining by foreign companies. It has been shown that mining has heavily intensified in the last few years due to the increased world demand for raw materials. It still represents, therefore, one of the biggest threats for rural communities. However, over the last three years, a new type of land grabbing has arisen. Foreign investors, both public and private, are taking control over vast stretches of fertile land for agricultural production in some of, but not only, the poorest countries in the world. This new form of land grabbing differs from land grabbing in the past, its dimension and its human rights implications (FIAN 2010, p. 8).

For the purpose of this analysis, *land grabbing* can be defined as taking possession of or control over a scale of land for commercial/industrial agricultural production that is disproportionate in size in comparison to the average land holding in the region. This definition does not focus on abusive practices in the process of acquiring the land but rather on the distributional aspects of the phenomenon and its impact on the political economy and the local and national populations' right to resources for both today and the future. This definition includes both national and foreign investors. In fact, the varying degrees of arrangements between foreign and national investors create a situation where the boundaries are blurred because the partnerships between the two result in foreign entities being treated as nationals. Nevertheless, focus should be made on the role of foreign investors because foreign land grabbing can be even more critical to human rights concerns than land grabbing by domestic actors due to the legal and practical difficulties faced by the territorial state in implementing its protect-obligation towards foreign actors. Moreover, foreign land grabbers normally lack a cultural relationship and corresponding responsibilities towards the affected communities. This can increase harm to the local communities and to their future generations with regards to cultural, social, and economic rights (especially the right to adequate food) (FIAN 2010, p. 8).

However, even if land grabbing is a broad term, the related current debates refer to the large-scale acquisition of land in developing countries by (foreign) companies or governments. These acquisitions have the positive potential to inject investment in agriculture and rural areas in countries where these investments are highly necessary. In opposition, the media as well as the international community observe the deals with increasing apprehension about the real impact of these investments in land. This concerns the effects of the deals on development and food security in general, and on the livelihoods of the local population in particular (Verie Aarts 2009).

To accurately identify the scope of this phenomenon, many organizations, including the United Nations' specialized agencies and NGOs, have started during the last several years to document and quantify this issue. However, quantifications and detailed information[11] are often inadequate due to the noted unwillingness of both governments and businesses with vested interests to fully disclose information on negotiations and deals made.[12]

The FAO estimates that in the last three years 20 million ha have been acquired by foreign interests in Africa specifying that the proportion of land under foreign control remains a relatively small proportion of total land areas—for instance around one percent in Ethiopia or Sudan (Hallam 2009). Meanwhile, in Africa, land leases, rather than purchases, predominate with durations ranging from the short term to 99 years. Host governments tend to play a key role in allocating land leases, not least because they formally own all or much of the land in many African countries[13].

Why Land Grabbing? A number of different factors have been identified as responsible for the growing trend of land grabbing. The increasing pressure to produce agrofuels as an alternative to fossil fuels is reported to have created an "*artificial demand (for agrofuels) that is unprecedented among cash crops, and which is likely to persist beyond the usual length of a 'commodity boom' cycle*" (Cotula et al. 2008). Other contributing factors are the global food crisis and the financial crisis. Since the expected profit per unit of land has increased as a result of higher agricultural prices, demand for farmland has driven up land prices in all regions (Braun and Meinzen-Dick 2009). Also, the food price crisis of 2007–2008 is said to have led to the proliferating acquisition of farmland in developing countries by other countries attempting to boost the security of their own food supply. To guarantee the food security of their own populations, a number of food-importing nations have started

[11] A 2009 study titled "Land Grab or Development Opportunity?" jointly produced by the Food and Agriculture Organization of the United Nations (FAO), the International Fund for Agricultural Development (IFAD) and the International Institute for Environment and Development (IIED), analyzed land acquisitions of 1,000 ha or more between 2004 and 2009 from Ethiopia, Ghana, Madagascar, and Mali (FAO, IFAD and IIED 2009). According to the study, about 2 million ha of land across the four countries had been signed over to foreign interests, including a 100,000 ha project in Mali and a 450,000 ha plantation for agrofuel in Madagascar. IIED (2009) identified a cumulative increase in land acquisition in the four countries with the past five years seeing an upward trend in both project numbers and allocated land areas; it also identified further growth of these activities. For example, in July of 2009, the Government of Ethiopia marked out 1.6 million ha of land, extendable to 2.7 million, for investors willing to develop commercial farms. The size of single acquisitions can be very large. Allocations include a 452,500 ha agrofuel project in Madagascar, a 150,000 ha livestock project in Ethiopia and a 100,000 ha irrigation project in Mali.

[12] See The Growing Demand for Land—risks and opportunities for smallholder farmers, Discussion Paper and Proceeding Report of the Governing Council Round Table held in conjunction with the Thirty-second Session of IFAD's Governing Council, IFAD, May 2009. Available at: http://www.un.org/esa/dsd/resources/res_pdfs/csd-17/csd17_crp_land.pdf.

[13] Malagasy Law No 2007–036 for instance stipulates "foreign natural or legal entities cannot directly have land access. However they are free, without any prior authorization, to agree to a renewable perpetual lease which duration cannot exceed ninety nine years". In Ethiopia the Government owns all the land, which is leased for periods from 20 to 45 years. Such leases vary in price depending on land use etc. (see Foreign Direct Investment in the Agricultural Sector in Ethiopia, EcoFair Trade Dialogue: Discussion paper No. 12 by Lucie Weissleder, University of Bonn, Heinrich Boll Stiftung, Misereor, October 2009. Available at: http://www.ecofair-trade.org/pics/en/FDIs_Ethiopia_15_10_09_c.pdf).

to purchase or lease land in developing countries, sometimes through sovereign wealth funds, to actually outsource their own food production (IFAD 2007).

According to the United Nations Conference on Trade and Development (UNCTAD), the biggest country investors in terms of outwards Foreign Direct Investment (FDI) stock in agriculture are, in descendent order: the United States, Canada, China, Japan, Italy, Norway, Korea, Germany, Denmark, and the United Kingdom (UNCTAD 2009, p. 118). Apart from the Gulf States, China, Korea, India, Japan, Libya, and Egypt appear among the major investors looking for fertile and water-abundant farmland (GRAIN 2008). However, EU countries and European private corporations are significantly involved. The reason why different countries are trying to control farmland abroad vary: whereas the Gulf States and China point to food security concerns, OECD countries seem to be supporting their food corporations in producing agrofuels, capturing new markets, and moving towards production (GRAIN 2008).

Following the recent financial crisis, actors within the finance sector are turning towards land as a source of solid financial returns (GRAIN 2008). While traditionally land acquisition has not been a typical investment for investment funds due to political obstacles and the lack of short-term returns, the food crisis and the demand for agrofuels has turned land into a new strategic asset. Indirectly, by increasing demand for agrofuels production, recent EU directives have increased demand for land by private finance institutions.

In terms of governance and human rights perspective, land grabbing has several consequences. The pressure on the land of peasants has increased with the multiplication of deals by which foreign investors (be they governments or Transnational Corporations, TNCs) acquire and control huge tracks of land. Evictions and land conflicts in general always represent situations in which human rights are very likely to be violated. This is true in all cases where the land is taken without respecting such basic international standards as prior comprehensive impact assessment, consultation, compensation, and rehabilitation. Moreover, the recent phenomenon of foreign states and companies taking possession of large surfaces in countries where hunger, vulnerability to climate changes, and extreme poverty are far from being solved, poses not only the immediate problems of violating the human rights to adequate food and housing, water and personal security linked to land conflicts and evictions, but also the issue of reduced land availability.

Land grabbing, even where there are no related forced evictions, drastically reduces land availability to land-scarce groups, reduces the political space for peasant-oriented agricultural policies, thus gears national markets towards agribusiness interests and global markets, rather than towards sustainable peasant agriculture for local and national markets and for future generations. This is particularly detrimental in societies where the peasantry counts for a large percentage of the population, hence the State's obligation to provide access to productive resources. From the perspective of human rights, of justice, peace, and sustainability, the new trend of foreign investors monopolizing land and related resources in other countries where people have increasing difficulties to feed themselves can hardly be considered a desirable solution. This situation undoubtedly undermines any strategy to promote pro-poor governance of land resources.

Security of Tenure Security of tenure refers to the degree of certainty that one's land rights will be recognized by others and protected in cases of specific challenges. One major component of security is, therefore, effective protection against the arbitrary curtailment of land rights with enforceable guarantees; and effective remedies against the loss of these rights. A second component is a reasonable duration of rights appropriate to the use to which the land is being put. A right to use land for a six month growing season may give a person sufficient security to invest in vegetable production, but the tenure is unlikely to be secure enough to encourage such long term—and sustainable—investments as planting trees or building irrigation systems. Beside, tenure security is important not only for agricultural production. It also allows poor rural people to diversify their livelihoods by using their land as collateral, renting it out, or realizing its value through sale. Land issues are certainly affecting the everyday choices of poor rural men and women. They influence the extent to which farmers are prepared to invest in their land or to adopt new technologies and promising innovations. In addition, land issues influence how poor rural people manage natural resources (IFAD 2010).

Many new factors cause tenure insecurity that, in turn, contributes to social instability and conflicts in many parts of the world. For example, recent concerns over high and volatile fuel and food prices prompted large-scale investments in the acquisition of agricultural land with view to increasing production of biofuels as well as food for investor countries with limited water and arable land. With the increasing prices of fuel and food, the new patterns of land investment are expected to continue. Farmers on state-owned land often have use rights that depend on the "productive use" of the land: governments may take the land and allocate it to others if productive use requirements are not met. These land rights are precarious when legislation does not define what constitutes productive use. The situation is even more insecure for the vast numbers of rural farmers who lack official proof of their land rights, often held under customary tenure. The lack of legal recognition of land rights has led to a perception that some countries have abundant land that can be used for large-scale agricultural investments, but in reality there is little land that is not already being used or claimed. As yet, few countries have adequate institutional mechanisms in place to protect the livelihoods of rural land users when large-scale land acquisitions for agricultural investment are being considered.

From a governance and sustainability perspective, several questions can be raised: what does "security" mean, for whom, and against what threats; who benefits and how from the present situation; how can security of tenure be realized at the scale of the challenge; what rights should be secure; and are there any risks associated with the process of providing tenure security?

Countries have adopted different strategies for addressing these questions. But in all cases, security of land rights remains a complicated affair. Land tenure systems are diverse and complex. They can be formal or informal, statutory or customary, permanent or temporary. Some are legally recognized, others are not. Some involve private ownership; others are based on common property. Meantime, there is no single land issue and no single solution. Legally registered individual land rights are not always the best solution for poor rural people. Many depend on more flexible, diversified, decentralized and common-property systems, where they can exert greater influence. Sometimes improved tenancy arrangement meets the needs of small and landless farmers better than private ownership. Formal, individual legal titles can be expensive and may benefit elite members of society more than poor rural people. Policy frameworks need to accommodate and build on customary norms and practices. In addition, it is often better to develop traditional administrative systems than to establish new, formal systems of land ownership. This is particularly true of communal and common-property lands which are very important to the livelihoods of poor rural people. Also, mechanisms for securing indigenous peoples' rights to their lands are important to cultural survival (IFAD 2010).

According to the World Bank Declaration on Land Governance in Support of the Millennium Development Goals, sustainable land governance should: provide transparent and easy access to land for all and thereby reduce poverty; secure investments in land and property development and thereby facilitate economic growth; avoid land grabbing and the attached social and economic consequences; safeguard the environment, cultural heritage, and the use natural resources; guarantee good, transparent, affordable, and gender-responsive governance of land for the benefit of all including the most vulnerable groups; apply a land policy that is integrated into social and economic development policy frameworks; address the challenges of climate change and related consequences of natural disasters, food shortage, etc.; and recognise the trend of rapid urbanisation as a major challenge to sustain future living and livelihoods.

Within a food security perspective, the FAO already has recommended that

> Nation-states should take measures to promote and protect the security of land tenure, especially with respect to women and poor and disadvantaged segments of society, through legislation that protects the full and equal right to own land and other property, including the right to inherit. As appropriate, States should consider establishing legal and other policy mechanisms that are consistent with their international human rights obligations and in accordance with the rule of law, and which enables land reform to enhance access to the poor and women. Such mechanisms should also promote conservation and sustainable use of land. Special consideration should be given to the situation of indigenous communities. (FAO 2005)

In sum, policy reform must recognize the many facets of land rights and usage. Above all, poor rural people must be able to participate in policy formulation and implementation to ensure their needs and concerns are adequately addressed and protected.

1.4 Conclusion

In the beginning of the current century, the world is facing critical global food and fuels shortages, climate change, urban growth, environmental degradation, and natural disaster-related challenges as today's world population continues to grow. This is placing inordinate pressure on the world's natural resources. Secure access to land and shelter is widely considered to be a condition for economic growth, poverty reduction, and food security enhancement. Each country sooner or later will have to deal with the management of land and with the four functions of land tenure, land value, land use, and land development in some way or another.

This chapter tried to highlight the key issues with regard to land resource governance and its dimensions in terms of sustainability and rural development by explaining the links among these areas and the related research and policy implications. The analysis has showed that poor land governance often tends to diminish investments in food security (i.e., agrobiofuel development) and encourages unsustainable practices of land management and use that generate short-term gains at the cost of environmental balance. Moreover, the land-grab trend, one of the consequences of poor land governance, is currently extending the private control over food production in a way that provides little transparency, few safeguards, and it shows little concern for political, (local) economic, or humanitarian consequences.

Based on these assumptions, we believe that the land resource governance is likely to become a key area of national and international concern, especially in the context of such global challenges as climate change, food crises, and energy shortages. In this context, sustainable land governance solutions that respect and strengthen the tenure rights and security for smallholder farmers, pastoralists, forest dependent people, and indigenous people are urgently required. We do believe that this measure is just one step on the road to promoting sustainability and rural development. To be effective, it should be complemented by pro-poor policies, services, and investments. Policies beyond the national level need to address such issues as migration, pastoralism, and conflicts that cut across regional and national boundaries.

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Chapter 2
Land Grabbing and Potential Implications for World Food Security

Shepard Daniel

Land is not just a resource to be exploited, but a crucial vehicle for the achievement of improved socioeconomic, biological, and physical environments.

Food and Agriculture Organization (FAO), 1999

Abstract During 2008, the emergence of "land grabbing" (the purchase or long-term lease of vast tracts of land from mostly poor, developing countries by wealthier, food-insecure nations as well as private entities to produce food for export) has raised deep concern over food security and rural agricultural development. This paper investigates land grabbing within the context of the global food crisis and the ways in which foreign investment in developing country land markets impacts land reform agendas and other policies to promote food security. While many argue that the establishment of a conducive investment environment is necessary to stimulate agricultural production, there is a pressing need to study the implications of increased foreign private control over crucial food-producing lands. By critically analyzing the combination of factors motivating this trend and the potential effects of such investments on agricultural production, this chapter incites important discussion about the role of the private sector in promoting—or hindering—global food security.

Keywords Land grab • Food security • Agricultural development • Investment • Private sector

2.1 Introduction

In the midst of the 2008 food and financial crises the world began to witness a "global land grab," a growing demand for land characterized by the purchase or long-term lease of vast tracts of land from mostly poor, developing countries by

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wealthier, food-insecure nations and private investors. Land with crop-producing potential is currently a valuable investment opportunity for nations who suffered from soaring prices of staple foods from 2006 to mid-2008 as well as for investors seeking new sources of financial gains amidst the economic downturn. So significant has this trend become that it has elicited widespread media coverage and concern from activists, researchers, and environmentalists that private land investments only increase monoculture-based, export-oriented agriculture, arguably jeopardizing international food security. Others, however, see these land investments as potential "win-win" situations in which food-insecure nations increase their access to food resources and "host" nations benefit from investments in the form of improved agricultural infrastructure and increased employment opportunities.

This paper examines the potential consequences of the global land grab, particularly highlighting how the land grab represents a major shift from public to private sector control over agricultural investment, and from domestic to foreign control over crucial food-producing lands. This discussion aims to contribute to the pressing need to study the ways such rapid land acquisitions by foreign entities will affect long-term food security as well as the implications of increased foreign private control over crucial food-producing lands.

2.2 Global Land Grab: Background

Land grabs—the purchase of vast tracts of land from poor, developing countries by wealthier, food-insecure nations and private investors—have become a widespread phenomenon, with foreign interests seeking or securing between 37 million and 49 million acres of farmland between 2006 and the middle of 2009 (Buying Farmland Abroad 2009). According to one international land development consultant, the current trend is "unprecedented in the context of arable land sales" (Rich Countries 2008).

The land grab phenomenon is the result of a complex combination of factors motivated by price volatility in global markets, the global food crisis, and high levels of speculative activity. However, there are three main trends driving the land grab movement: the rush to secure food supply by increasingly food-insecure nations, the surging demand for agrofuels and other energy and manufacturing demands, and the sharp rise in investment in both the land market and the soft commodities market. The following section takes a closer look at each issue.

2.2.1 Driving Forces Behind the Land Grab

The acquisition of foreign land for crop production is considered both politically and financially strategic. Both private firms and government entities are turning to foreign lands in hopes of turning a profit in an unstable market and averting potential domestic upheavals over food price and supply. This section describes three significant motivational factors behind the trend: securing food supply, acquiring energy and manufacturing resources, and generating profits from private investments.

2.2.1.1 Securing Food Supply

A number of factors threatening food security—including the 2008 food price crisis and consequent increasing import bills and inflation rates, harsh climatic conditions, poor soils and scarce land and water in many areas, combined with economic and demographic growth—have led many nations, particularly in the Middle East and Asia, to reexamine domestic food security policies. Many governments are looking to stabilize supplies by acquiring foreign lands for food production in the hopes of averting potential domestic upheavals over food price and supply. Fears of a global food shortage are still valid as food prices continue to remain high and food emergencies persist in 31 countries (FAO 2009).

The Gulf States, with scarce water and soil resources on which to grow food, but vast oil and cash reserves, have watched their dependence on food imports become increasingly uncertain and ever more expensive, their total food import bill ballooning from US$ 8 billion to US$ 20 billion from 2002 to 2007 (GRAIN 2008). These states have moved quickly to extend control over food-producing lands abroad. Qatar, with only 1% of its land suitable for farming, has purchased 40,000 ha in Kenya for crop production and recently acquired holdings in Vietnam and Cambodia for rice production, and in Sudan for oils, wheat, and corn production (Kenya 2009). The United Arab Emirates (UAE), which imports 85% of its food, purchased 324,000 ha of farmland in the Punjab and Sindh provinces of Pakistan in June 2008 (Kerr and Farhan 2008). Other emerging nations such as China, Japan, and South Korea are also seeking to acquire land as part of a long-term strategy for food security.

2.2.1.2 Energy and Manufacturing

A surging demand for agrofuels (biofuel produced from ethanol and sugarcane as well as biodiesel) and access to new sources of raw materials for manufacturing goods is also driving land purchases. The demand for agrofuels has increased rapidly over the past several years as oil-dependent countries establish ambitious targets for agrofuel production and for incorporating biodiesel and bioethanol with traditional transport fuels. For example, the US Renewable Fuel Standard aims to increase ethanol use by 3.5 billion gallons between 2005 and 2012, and the European Union (EU) aims to increase the proportion of biofuels used in land transport to 10% by 2020 (Oxfam 2008). With these and other impetuses, the use and production of biofuels has skyrocketed in recent years such that the quantity of US corn used to produce ethanol increased by 53 million t between 2002 and 2007 (accounting for 30% of the total global growth in wheat and feed grains use) (Mitchell 2008).

Attracted by this big demand and market, investors—mainly from the private sector and OECD member countries—are targeting vast tracts of land to produce crops for agrofuels in developing countries, which generally have a comparative advantage in such production—for example, due to low labor and land costs and, in some cases, land availability (Haralambous et al. 2009). In Indonesia, PT Daewoo Logistics Indonesia, a subsidiary of South Korea's Daewoo Logistics Corporation, and Cheil Jedang Samsung recently announced a partnership to invest US$ 50 million to grow and process energy crops on the Indonesian islands of Buru and Samba. The two companies will produce 30,000 t of corn grain a year on 24,000 ha and will export their entire production back to South Korea (South Korean Investors 2009). In early 2008, Sinopec and the Chinese National Overseas Oil Corporation, two state-owned oil giants, made investments of US$ 5 billion and US$ 5.5 billion respectively, also in Indonesia, to grow and process corn into biofuel to be exported to China (Sinopec 2008).

2.2.1.3 Private Investments

Also fueling the land grab is the hunger of investors who have identified farmland as an important investment posed to produce significant returns. Many Western investors including Wall Street banks and wealthy individuals have, since 2008, turned their attention to agricultural acquisitions. Morgan Stanley purchased 40,000 ha of farmland in the Ukraine, Goldman Sachs took over the rights of China's poultry and meat industries—including the rights to their farmland—in September 2008, and BlackRock, Inc., a New-York based money manager, set up a US$ 200 million agricultural hedge fund, US$ 30 million of which will be used specifically to acquire farmland (Montenegro 2009). Furthermore, the Swedish investment groups, Black Earth Farming and Alpcot-Agro, along with the British investment group Landkom collectively acquired nearly 600,000 ha in Russia and Ukraine, while Al Qudra, an Abu Dhabi-based investment company, bought large tracts of farmland in Morocco and Algeria, and is reportedly closing in on purchases in Pakistan, Syria, Vietnam, Thailand, Sudan, and India (Montenegro 2009).

This increased attention from investors can be partially explained by the recent shift of focus from the "hard" to the "soft" commodities market. Traditionally, land markets have not provided the most effective returns on investment as land presents myriad problems for investors whether related to access, security, use, or consistency. However, the recent private sector push into farmland acquisition has occurred at a dizzying speed as land markets and "soft commodities" have suddenly become attractive investments. There are several reasons for this shift: In 2007, "soft" commodities overtook their "hard" counterparts as the prime performers in the commodities investment market. Researchers have sited forces such as strong demand from emerging economies such as China, India, Central Europe, and South America, as well as new demands from bioenergy and other "bioproducts" from agricultural crops among the causes of this "bull run" on soft commodities (Bidwells

2007). It became apparent in late 2007 that investors were increasingly looking to gain direct exposure into soft commodities markets through investment in land, farming, and associated activities (Bidwells 2007). Throughout 2008, those hoping to capitalize on commodities fundamentals as well as on markets with fast-growing demand continued to invest in land and in operational farming around the world.

2.2.2 Land Acquisitions and Developing Countries: A Win-Win Situation?

In the context of this surging demand for fertile land, nation after nation has entered the land market, with Kenya, Sudan, Ethiopia, Zimbabwe, Tanzania, Cambodia, Philippines, the Ukraine, and others offering land for lease or purchase. In many underdeveloped countries, a lack of skills, infrastructure, and capital results in the underutilization of potential lands and resources for food production. African governments have been known to mismanage agricultural resources, and they additionally suffer from a lack of capital and technological expertise to effectively harness agricultural resources (Africa's Silver Lining 2008). With buyers now willing to invest millions to put farmland to productive use, these less-developed nations are hopeful that land deals will bring much needed investment in infrastructure and agricultural technology as well as increased employment.

Many African nations, especially in Sub-Saharan Africa, view this demand as an important, timely opportunity for the continent's economic development. For example, Awad al Karin, Minister of Investment in Sudan, has stated, "Sudan can feed the whole world thanks to our millions of hectares of fertile land" (Sudan's Rural 2009). Furthermore, Madagascar's Minister of Economy, Ivohasina Fizara Razafimahefa, has expressed the view that "Africa is offering one of the few opportunities in the world where return on investment is still high and where the risk of investment is relatively small. The message we want to convey is: Africa…can bring solutions to this current crisis instead of always being considered as a problem to the world economy" (Sudan's Rural 2009).

Indeed, a great deal of discussion has surrounded the land grab phenomenon suggesting that the trend could be a win-win situation both for "host" or recipient nations as well as foreign investors. In describing the land grab, Paul Mathieu of the United Nations Food and Agriculture Organization (FAO) says that the buying up of arable land "is a phenomenon of huge magnitude" which has undergone "a sudden acceleration." He acknowledges, "more investment capital in agriculture, when well-managed, can contribute to real rural development." "There may be very positive practices in the negotiations between outside investors and the local community, in which both are looking for a win-win situation" (Zamora 2008).

In the same way, FAO Director-General Jacques Diouf, while having clearly expressed his concern about the potential consequences of swift land grabbing on political stability, has said he supports the proposed Gulf food deals as a means of economic development for poor countries. If the deals are constructed properly, he said, they have the potential to transform developing economies by providing jobs both in agriculture and other supporting industries like transportation and warehousing (Coker 2008). The president of the International Fund for Agricultural Development (IFAD) has also expressed hope for possible development opportunities through land purchases. “When such deals take into account interests of both parties they help increase agricultural production in developing countries, provide jobs, boost export and bring in new technologies to improve farm efficiency there” (Kovalyova 2009).

While the rhetoric surrounding the possibility of win-win scenarios for investors as well as developing nations has grown in recent months, the dissenting voices from other actors often go unheard. Despite calls from several organizations (including the United Nations and IFPRI) for an international code of conduct for land acquisitions,[1] most of the land deals to date lack transparency and offer little or no concession to small famers. In general, there is little evidence that rural economies and livelihoods are being factored in to whether or not these situations will, in fact, be win-win. The following sections attempt to clarify such impacts and to draw the important connection between the well-being of the rural poor and overall world food security.

2.2.3 The Land Grab and Increasing Global Food Security

There is no denying that food security remains a dire problem: rapidly rising prices for staple foods from 2006 to 2008 culminated in a worldwide food crisis, and while commodity prices have somewhat stabilized, millions are still suffering from hunger. FAO reports indicate that another 40 million people were pushed into hunger in 2008, primarily due to higher food prices, bringing the overall number of undernourished people in the world to 963 million (compared to 923 million in 2007). While supply shortfalls are a normal part of agriculture, and historically, a supply shortfall triggers increased production through higher prices, the current crisis is comprised of unique elements including uncontrolled financial speculation, new demand on agricultural commodities from the agrofuels sector, mounting stress on the quantity and quality of soil and water available, and the uncertainty of how climate change will affect growing conditions (Murphy 2008).

World leaders gathered at the FAO in Rome in June 2008 to address the crisis and seek consensus on solutions. The Conference Declaration put forward a two-track response to the crisis: (1) boost production by investing in the agricultural sector and rural development, and (2) ensure immediate access to food for the poor and

[1] IFPRI’s April 2009 publication, “Land grabbing by foreign investors in developing countries: risks and opportunities,” calls for a code of conduct both for foreign investors and the host countries in order to protect the interests of small farmers, as well as address environmental concerns on biodiversity and water and land resources stemming from the impact of large-scale farmland investments.

vulnerable in both rural and urban areas by providing social safety nets and protection measures. The first component—increasing investment in agriculture and figuring out the most appropriate way to do so given the urgency and fragility of the situation—must be analyzed within the context of increasing commercial pressure on land markets. Is the land grab an effective response to the need to increase investment in agriculture or is it diverting decision-makers from more effective solutions?

2.3 Implications and Potential Consequences

The land grab trend has come under heavy scrutiny since mid-2008. On the one hand, investment in agricultural land is thought to be an answer for boosting food production in a world plagued by food shortages; on the other hand, many claim that this large-scale, private-sector-led approach conflicts with the urgency of increasing domestic food supplies in the world's poorest and most vulnerable countries. While there is talk of both the risks and opportunities of foreign land acquisitions for the poor, this paper considers whether the most important questions remain at the forefront of the debate; most importantly, *where does the urgent and critical task of increasing food security fall within the accelerating trend of commercial investment in farmland?*

2.3.1 Displacement of Small Farmers

No matter how convincing the claim that the global land grab will bring much-needed agricultural investment to poor countries, evidence shows there is simply no place for the small farmer in the vast majority of these land grab situations. Most land deals consider the local population only to the extent that large-scale agriculture will create employment for subsistence farmers and rural land-dwellers. However, the extension of employment to local farmers to work on industrial, plantation-style farms effectively implies the forcing of subsistence farmers off their land to make room for large-scale farms producing food for other countries. Not only does land grabbing mean that farmers will lose their land, but these lands will be transformed from smallholdings or communal lands into large industrial estates connected to far-off markets (GRAIN 2008). The chairperson of the United Nations Permanent Forum on Indigenous Issues estimates that the land rights of 60 million indigenous people worldwide may be at risk as a result of large-scale agro-fuel expansion (Haralambous 2009).

Drawing great attention to this issue was the proposed land deal in Madagascar, where Daewoo Logistics planned to lease half of all the arable land in the country; 70% of the Malagasy people live in rural areas—meaning thousands were to be displaced or forced into Daewoo employment. Madagascar's citizens were outraged that their government was posed to cede an implausible amount of land to the South

Korean corporation. A program officer from Madagascar's Farmers Confederation (Fekritana) expressed, "One of the biggest problems for farmers in Madagascar is land ownership, and we think it's unfair for the government to be selling or leasing land to foreigners when local farmers do not have enough land. Our concern is that first of all the government should facilitate the access to land by local farmers before dealing with foreigners" (Zigomo 2009).

Similarly, the situation for small farmers in the Punjab province of Pakistan, where the UAE purchased 324,000 ha (800,000 acres) in May 2008, is "very grave." Over 6 million families work around 50 million acres of land in the country, and 94% of these people are considered subsistence farmers, each occupying less than an average of 12.5 acres (Fraz Khan 2008). In many cases, these are tenants working large private holdings or government land, and they have been farming this land for generations (Husain 2009). Pakistani farmers' movements are warning that 25,000 villages will most likely be displaced due to the signing of this deal (Fraz Khan 2008).

The problem of small farmer displacement is also motivated by the soaring demand for agrofuels. It has become evident that US and EU biofuel targets cannot be met with solely local production, and this has led to substantial land investments for agrofuel production in Ghana, Senegal, Mozambique, Guatemala, and Brazil with smallholder farmers being displaced in the process (ActionAid 2008). In Ghana, for example, there is literally a scramble for land by multinationals and local companies in partnership with foreigners vigorously pursuing plans in cultivation of the jatropha plant for its prized oil seed to produce biodiesel for export (Dogbevi 2009). Over 20 companies from various countries are acquiring land in Ghana to cultivate non-food crops and other crops for the production of ethanol and biodiesel, mostly for export. Ghanaian farmers are starting to realize what the agrofuels boom is doing to their livelihoods, and resistance is growing. Farmers in northern Ghana have rejected jatropha as an agrofuel, mainly because they fear being tied down by fickle markets, and because of its toxicity, which limits its use (GRAIN 2007). The African Biodiversity Network has severely criticized the United Kingdom (UK) for setting targets for biofuels that will sacrifice Africa's land, forests, and food to satisfy the UK's vast energy requirements (GRAIN 2007).

2.3.2 Effects on Land Reform

Another danger of the land grab movement is that commercial land deals are coming into direct conflict with land reform efforts in many developing countries. Conflict between rural land dwellers and commercial interests is not a new phenomenon. Mounting demand for land due to demographic and economic growth and resource depletion increasingly leads rural areas to be incorporated into market economies, and therefore governments often experience pressure to implement land reform—new policies that give the poor secure access to land, thereby allowing them to pursue their livelihoods without fear of harassment or eviction.

The task of achieving food security and the implementation of land reform policies in developing countries are inextricably linked. There are 1.5 billion small-scale farmers in the world who live on less than 2 ha of land;[2] secure and equitable access to and control over land allows these farmers to produce food, which is vital for their own food security as well as that of rural populations throughout the developing world. The current land grab—characterized by unprecedented pressures on land resources and increasing demand within land markets—is placing new tensions on land tenure systems. Those most at risk of losing access to land are small-scale producers who do not have formal tenure over the land that they use, as well as women, indigenous people, pastoralists, and fisher-folks (International Land Coalition 2008).

The global food and financial crises have made land reform an even more urgent task, but land deals threaten such reforms. In the Philippines, for instance, a series of high-profile deals have clashed with long-running demands for agrarian reform, including land redistribution (Qatar Land Deal 2009). Reportedly the Philippines finally began to push a land reform bill, the Genuine Agrarian Reform Bill (GARB), through the House in May 2009 (Padilla 2009), but this development has foreign investors worried. For instance, Saudi executives representing big agricultural businesses have raised concerns about the Philippine agrarian reform; reportedly, Saudi investors were planning to acquire thousands of hectares of land for planting, processing and raising livestock and poultry, and some also expressed the possibility of planting cassava and sugarcane (Cayon 2009).

In the Philippines, implementing agrarian reform has the potential to stimulate domestic economic activity and help address the problem of massive job dislocation. Those directly and indirectly involved in agricultural production in the Philippines comprise around 70% of the labor force, and their combined production accounts for almost 75% of the domestic economy. However, in the absence of agrarian reform, a huge portion of the labor force is thus denied access to gainful, secure, and sustainable employment. As a consequence, nearly 70% of the poor live in the countryside, and around 90% of the rural population lives below the poverty line (Cayon 2009).

The discussion of land reform in relation to the land grab trend has received little media or scholarly attention. In many cases, land reform is critical to achieving the rural development necessary for domestic food production. Other countries in which land reform is needed but may be threatened by extensive land deals include Kenya, Tanzania, and Zimbabwe.

2.3.3 *Local Food Security in Jeopardy*

A dangerous element of the land grab trend is the shift from domestic to foreign control over food resources and food-producing lands. Land deals diminish the

[2] According to the International Land Coalition (ILO).

possibility of reaching food self-sufficiency for poor nations and some view land concessions as governments out-sourcing food at the expense of their most food-insecure citizens. Importantly, most of the target or "host" countries themselves are net food importers or even emergency food aid recipients (see Table 2.1). For instance, Madagascar and the Sudan still receive food aid relief from the World Food Program; several months ago, Cambodia received US$ 35 million in food assistance from the Asian Development Bank (ADB) (Haralambous et al. 2009). For nations experiencing social unrest and high rates of hunger and poverty, it is hard to conceive that fertile land is being conceded to foreign countries instead of being used to boost domestic production.

Kenya has received much attention as the Qatari government is to fund a US$ 3.4 billion port off the coast of Kenya in exchange for a lease of 40,000 ha of land on which Qatar will grow crops (Montenegro 2009). According to land law, this area belongs to the local community; however, pastoralists and farmers in the Tana delta are largely illiterate and unaware of their legal rights (Montenegro 2009). This deal seems unthinkable given that Kenya is currently in a state of "food emergency" according to the FAO, which reports Kenya as experiencing "exceptional shortfall in aggregate food production and supplied" (see Table 2.1). Recent drought has left 10 million people hungry and post-election violence in 2008 displaced thousands of farmers throughout the country's most fertile regions; reportedly, 30% of Kenyans now face food shortage (Kilner 2009).

Moreover, in Cambodia, where an unusually stable economy is inviting a new wave of foreign investment, the competition for fertile farmland is fierce. With Qatar, Kuwait, and UAE all striving for land deals, the Cambodian government continues to clear a path for foreign investment, seemingly ignoring the ever-growing burden of rural landlessness and food shortage in the country. The Cambodian government has positioned itself as a solution to the food crisis, pointing out that of Cambodia's 6 million ha (about 15 million acres) available for cultivation, only 2.5 million are currently used (Montero 2008), and yet, at the same time, tens of thousands are estimated to have been displaced in Cambodia in recent years (Montero 2008), and widespread rural poverty still hampers access to adequate food for the 33% of Cambodian citizens facing undernourishment, according to the most recent FAO statistics (FAO 2008).

It is difficult to visualize a win-win scenario when governments do not prioritize domestic food supply or local production over foreign investment and production for export. Evidence shows that deals often lack transparency and are subject to mismanagement by governments. An extensive May 2009 report found that many countries do not have sufficient mechanisms to protect local rights and take account of local interests, livelihoods, and welfare (Vermeulen and Cotula 2009). Moreover, local communities are rarely adequately informed about land concessions made to private companies (e.g., Cotula et al. 2008). Insecure local land rights, inaccessible registration procedures, vaguely defined productive use requirements, legislative gaps, and other factors too often undermine the position of local people. Without the careful assessment of local contexts, including recognizing existing land uses

Table 2.1 Countries in crisis requiring external assistance (total: 32 countries). (FAO 2009)

Nature of food insecurity	Main reasons
AFRICA	
Exceptional shortfall in aggregate food production/supplies	
Kenya	Civil strife, adverse weather, pests
Lesotho	Low productivity, HIV/AIDS pandemic
Somalia	Conflict, economic crisis, adverse weather
Swaziland	Low productivity, HIV/AIDS pandemic
Zimbabwe	Deepening economic crisis
Widespread lack of access	
Eritrea	Internally displaced persons (IDPs), economic constraints
Liberia	War related damage, pests
Mauritania	Several years of drought
Sierra Leone	War related damage
Severe localized food insecurity	
Burundi	Civil strife, internally displaced persons (IDPs), and returnees
Central African Republic	Refugees, insecurity in parts
Chad	Refugees, conflict
Congo	Internally displaced persons (IDPs)
Côte d'Ivoire	Conflict related damage
Democratic Republic of Congo	Civil strife, returnees
Ethiopia	Insecurity in parts, localized crop failure
Guinea	Refugees, conflict
Guinea-Bissau	Localized insecurity
Sudan	Civil strife (Darfur), insecurity (southern Sudan), localized crop failure
Uganda	Localized crop failure, insecurity
MID-EAST and ASIA	
Exceptional shortfall in aggregate food production/supplies	
Iraq	Insecurity and insufficient rainfall
Widespread lack of access	
Afghanistan	Conflict and insecurity, inadequate rainfall
Dem. People's Rep. of Korea	Economic constraints
Severe localized food insecurity	
Bangladesh	Past floods and cyclone
Iran	Past drought
Nepal	Poor market access and past drought/floods
Myanmar	Past cyclone
Sri Lanka	Conflict
Tajikistan	Winter crop damage, poor market access, locusts
Timor-Leste	Internally displaced persons (IDPs)
LATIN AMERICA	
Severe localized food insecurity	
Cuba	Past floods and other hurricane damage
Haiti	Past floods and other hurricane damage

and claims, securing land rights for rural communities, and involving local people in negotiations, land acquisitions will inevitably produce adverse affects for local food production and rural livelihoods.

The following section examines those actors encouraging the land grab trend by seeking to improve investment climates in developing countries. To examine the effects of land acquisitions is not only to consider the direct consequences for rural development and livelihoods but also to question the very strategies of development aiming to boost food production.

2.4 Increasing Investment in Agriculture: In Whose Interest?

2.4.1 The Role of International Financial Institutions

In response to the global food crisis, the World Bank and other International Financial Institutions (IFIs) put forward several recommendations for developing countries. Short-term measures included scaling up social safety nets and eliminating tariffs on key food items. In addition, the World Bank established the Global Food Crisis Response Program (GFRP), characterized by "fast-track" spending of up to US$ 1.2 billion of the Bank's resources within the next three years for alleviating hunger (The World Bank 2008). Less apparent, however, is the role of the IFIs in encouraging increased private investment in agriculture in the wake of the food crisis.

Among those fomenting extensive land deals in agriculture is the International Finance Corporation (IFC), the private sector arm of the World Bank Group. The IFC promotes economic growth in the developing world by financing private sector investments and providing advice to governments and businesses. The IFC plays a catalytic role, by mobilizing additional capital through loan syndication and by lessening the political risk for investors, enabling their participation in a given project.[3]

Also working to facilitate private investments in developing country agribusiness and the land market is the Foreign Investment Advisory Service (FIAS), a multi-donor service of the World Bank Group (WBG) managed by IFC[4]. FIAS'

[3] While the World Bank (IBRD and IDA) provides credit and non-lending assistance to governments, the IFC provides loans and equity financing, advice, and technical services to the private sector. The IFC is one of the fastest growing institutions in the World Bank Group and has many important investments to improve local private sector companies, but its projects have often been carried through at the expense of physical and economic displacement for thousands. Source: Bank Information Center (BIC).

[4] FIAS had its start as an IFC program, following a 1985 request from the Chinese government for advice on their foreign investment legislation. FIAS is now funded by IFC, MIGA, and the World Bank, as well as bilateral donor partners. It includes staff from each of the three WBG organizations.

mission is "to help developing countries improve their business environments to increase private sector activity and investments with positive development impact." FIAS' work promotes private investment in land markets by bettering the "investment climate" of developing countries based on indicators of "trade impact," gross fixed capital formation, GDP, export performance, and number of new business registrations in a given time period.

In the context of land grabbing, IFC and FIAS encourage land leases and purchases by assisting private investors interested in agribusiness investment in developing countries. They contribute to building the infrastructure necessary for private economic action in the developing world, and their investments capitalize on the fact that high food prices have triggered a "financial revolution" in the agricultural sector—a sector which has long struggled with underinvestment. Throughout the financial world, agribusiness private equity funds investing in farmland are now emerging as an asset class, and in 2008, the IFC spent a total of US$ 1.4 billion in the agribusiness supply chain, of which US$ 900 million went directly to agribusinesses (Godoy 2009).

The type of agriculture promoted by such investments in agribusiness is large-scale and capital intensive. This is evidenced by the recent partnership formed between IFC and Altima Partners to invest in farming operations and agricultural land in "emerging market countries." The new fund, the US$ 625 million Altima One World Agricultural Development Fund, is IFC's largest equity investment in its expanding agribusiness portfolio. The fund aims to identify "farming talent" in developing countries and help them expand farm production with the help of additional capital and new technologies (Godoy 2009).

In addition, with IFC and FIAS assistance, many countries have reduced or eliminated laws that prohibit foreign ownership of land. For instance, IFC and FIAS are currently working with Madagascar officials to cut down on the number of licenses required to start a business. They have also encouraged countries to reduce demands on foreign companies to keep profits in the country, making it more attractive for foreign companies to invest. This has facilitated the use of agricultural land for export production.

2.4.2 Considerations for Food Security

This financial infrastructure encouraging private investment with the goal of boosting agricultural productivity is clearly positive for investors, but what does it mean for farmers in developing countries and for global food security? The IFC's focus on solely the private sector through investment in agribusiness is promoting a type of agriculture that is potentially dangerous to the world's rural poor in a number of ways.

In the first place, making way for foreign investors interested in large-scale food production discourages traditional farming methods utilized by millions of small farmers. The IFIs' approach has been described as "de-peasantization"—the phasing out of a mode of production to make the countryside a more receptive site for intensive capital accumulation (Bryceson 1999). This approach to development clashes fundamentally with the findings of several studies, which indicate that rural economies and traditional forms of agriculture are imperative for the health of economies in many developing countries. For example, the three-year high-level study, the International Assessment of Agricultural Knowledge, Science, and Technology for Development (IAASTD) emphasizes food security, environmental sustainability, and traditional knowledge, while criticizing trade liberalization for undermining the agricultural sector and stresses the need to "preserve national policy flexibility" (IAASTD 2008).

A second aspect that begs further examination is the IFIs' support for agriculture based on genetically modified seeds and intensive technology inputs. In February 2009, IFC joined forces with the Alliance for a Green Revolution in Africa (AGRA), a partnership among several organizations aimed at developing solutions to significantly boost farm productivity and incomes for the poor in Africa.[5] AGRA advocates for policies that support its work across all key aspects of the African agricultural "value chain"—from seeds, soil, and water to markets. It is aimed at small farmers and promotes the use of agricultural technology and genetically modified seeds, which it believes to be the best way to increase agricultural productivity in Africa.

The partnership between IFC and AGRA, which began in February 2009, is meant to help unlock credit and financing for small-scale farmers and agribusinesses across sub-Saharan Africa and will focus on developing market-based incentives and tools to increase agricultural productivity (IFC, AGRA 2008). For example, the two institutions will work together to scale up AGRA's partnerships with investors and national commercial banks to make loans available to farmers and agribusinesses like smaller seed companies (Makunike 2008).

An overwhelming number of critics, however, argue that the AGRA approach to ensuring food security is part of the problem rather than the solution.[6] Many warn that AGRA is actually the philanthropic flagship of a large network designed to "attract private investment, enroll African governments, and convince African farmers to buy new seeds and fertilizers" (wa Ngugi 2007). One need only look to the historical precedent of the Asian green revolution, "the science-based transformation of Third World agriculture": the IR8 rice variety that could produce more grains of rice per plant when grown with certain fertilizers and irrigation was subsidized and GMO-based agriculture was promoted throughout Asian countries; however, after initial subsidies were phased out, many Indian farmers lost their land to banks when they were unable to repay money they had borrowed for the purchase of agricultural

[5] AGRA is already backed with a US$ 150 million start-up grant from the Gates Foundation and the Rockefeller Foundation, and ex-secretary-general of the United Nations, Kofi Annan, serves as its chairman.

[6] See compilation of sources from the Oakland Institute: "Voices from Africa," an online clearinghouse to share information on and promote alternatives to the New Green Revolution in Africa: http://www.oaklandinstitute.org/voicesfromafrica.

inputs such as hybrid seeds, fertilizers, and pesticides (e.g., Shiva 1992). As one critic argues,

> The green revolution in India really was the pauperization of the poor Indian farmer. AGRA's promise to follow the Asian model means small-scale African farmers will be strangled by ever widening circles of dependency and debt…. Once the mask of philanthropy is removed, we find profit-hungry corporations vying to control the seed market in African countries, create a path for Genetically Modified seeds and foods, and to pry open a market for chemical fertilizers—which in turn will have an adverse effect on African indigenous seed populations and destroy biodiversity, not to mention the devastation of the environment and the salinization of the soil. (wa Ngugi 2007)

One non-governmental organization describes the idea of a green revolution as "a scientific reductionism," which has resulted in monocultures, the use of chemical inputs (such as fertilizers and pesticides) and increased mechanization. "This is alien to Africa's peasant farming systems, which pursue a more holistic approach to agriculture in which crops are combined with livestock, organic manure is used, soils are looked after, and there is a deep respect for the wider environment" (Makunike 2008).

A third point to consider is the very question of how a given development approach defines "*productivity*." The IFC and other IFIs, by supporting AGRA and capital-intensive agribusiness are encouraging a high-technology, high-input mode of agriculture, claiming it to be the most "productive" way to increase yields and therefore increase output in food products. However, the meaning of "productivity" is itself debatable.

Agribusinesses and economists tend to use "yield" measurements when calculating the productivity of farms. Yield can be defined as the production per unit of a single crop. For example, a corn farm will be judged by how many metric tons of corn are produced per acre. It is true that the highest yield of a single crop is often achieved through industrial monocultures, and smaller farms can rarely compete with this monoculture single-crop yield. However, because small-scale farms use "inter-cropping" methods to plant other crops where single-crop monocultures have empty "weed spaces," and because small farmers are more likely to rotate or combine crops and livestock with the resulting manure replenishing soil fertility, these small-scale integrated farms produce far more per unit area than large farms. Though the yield per unit area of one crop—corn, for example—may be lower on small-scale farms, the total output per unit area (with small farms often producing more than a dozen crops and numerous animal products) is nearly always higher than that of larger farms (Kimbrell 2003).

Continuing to measure farm efficiency through single-crop yield in agricultural economics, represents a bias against diversification, and reflects the bizarre conviction that producing one food crop on a large scale is more important than producing many crops (and higher productivity) on a small scale (Kimbrell 2003). Countless studies have challenged the conventional wisdom that industrial farms are more efficient by demonstrating the virtues of small farms as "multi-functional"—that is, more productive, more efficient, and able to contribute more to economic development than large farms (Rosset 1999). Why not aim to promote more integrated, sustainable farming methods for multi-functional farms for the seven out of ten Africans (Africa's Smallholder 2009) who are small producers rather than imposing monoculture, large-scale production?

2.5 Concluding Remarks: Putting Food Security Back in the Forefront

The land grab movement demonstrates that there are several factors dividing the debate surrounding agricultural investment which have important implications for global food security. First, there exists a key divide about the roles to be played by the state and the market. The role of the IFIs within the land grab trend and in response to the global food crisis represents an approach to development characterized by private sector control and lower government regulation. Their solution for increasing food security is to increase agricultural "productivity" through large-scale intensive agriculture, but in many cases, their approach has little to do with food security for the world's most vulnerable. At a very minimum, regulation and oversight is necessary to the extent that domestic food supply can be ensured.

A second divide is over the role of science and technology in agriculture. The IFIs' appeal for increased investments in agribusiness and high-input, capital-intensive agriculture will undoubtedly have adverse effects on rural livelihoods. The assumption that capital-intensive technologies through agribusiness will trickle down to the poor is misleading, as rural communities will be displaced and food sovereignty undermined.

A third key divide in this debate is over the role of international trade in agriculture. Food-insecure countries are responding to food shortages by looking to distant lands in order to develop crops for export back home. However, should free trade be supported at the expense of domestic food supplies? The land grab trend is putting private interests in direct competition with land for local food production, a situation which cannot be tolerated in the face of food insecurity.

Increased food supply does not automatically mean increased food security for all. What is important is who produces the food, who has access to the technology and knowledge to produce it, and who has the purchasing power to acquire it. The conventional wisdom is that, in order to double food supply, we need to redouble efforts to modernize agriculture. However, there is ample evidence suggesting the limitations of such systems to reduce food poverty. The poor and hungry need low-cost and readily available technologies and practices to increase local food production (Pretty and Hine 2001). The real question is not how to increase productivity yields but rather the extent to which farmers can improve food production with cheap, low-cost, locally available technologies and inputs.

Much of the global food system, from seed and fertilizer supply to trade and retail, is in the hands of a few large corporations whose interests are first and foremost economic gain, not feeding the millions of the world's hungry. The land grab trend is extending the control of the private sector over food production in a way that provides little transparency, few safeguards, and shows little concern for political, (local) economic or humanitarian consequences. The presumed virtues of market mechanisms and of increasing investment climates dominate the global agenda, blinding decision-makers to the reality of peoples' basic needs and to the simple fact that domestic food supply must be ensured. Put quite simply, private corporations are not providing short- or long-term stability in food production and supply for the developing world. The price volatility resulting from increased corporate control of food trade is hugely damaging to farmers' livelihoods and to poor countries dependent on a system that has not proved to come through for them.

Food security is a problem for the world's most vulnerable. It is a problem for the 963 million people in the world who are chronically hungry. These people are the rural poor, the subsistence farmers, the 1.5 billion small producers who each farm less than 2 ha of land. The hungry are the 100,000 families in the Punjab province in Pakistan and the hundreds of soon-to-be displaced Kenyan farmers. They are the ones who are suffering, and yet they are not the ones who are benefitting from land market investment. When will we stop talking about win-win scenarios and recognize that the real problem is about those whose interest is left out of the land purchases and assessments of investment climates? This fundamental disconnect between increasing investment and increasing food security is a dangerous problem that is only exacerbated by the commercial land acquisitions that comprise the global land grab movement.

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Chapter 3
Turning Adversity into an Advantage for Food Security Through Improving Soil Quality and Providing Production Systems for Marginal Saline Lands: ICBA Perspectives and Approach

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Abstract Continuing population and consumption growth demand more food in the developing world, where most of the farmers are resource-poor smallholders and face multifaceted challenges to meet increasing food demand for their families and livestock from good as well as marginal/saline lands. This can be attributed to water scarcity, poor understanding of the problem, lack of access to new technology, financial constraints, and diminished soil and water quality. Owing to this menace, many farmers have set aside marginal lands and abandoned agriculture on these lands. Producing more food from the same area of land while reducing the environmental impact requires sustainable intensification. Rather than wringing their hands in despair over these problems, the scientists of the Dubai-based International Center for Biosaline Agriculture (ICBA) are turning adversity into advantage by providing technical support to poor farmers through the National Agricultural Research Systems (NARS) of respective partner countries in improving soil quality and by providing alternative agricultural production systems to farmers for better agricultural services, which lead to improvements of their livelihoods and food security. These practices include initial soil and water resources assessment for better understanding of resource quality to develop site-specific management plans (site preparation, use of soil amendments, leaching excess salts, salinity mapping and monitoring, nutrient management, and other cultural practices), and provision of production system that fit these conditions. The initial plan helps farmers to take necessary actions to improve and maintain soil health during the course of crop growth and to assure that soil quality is not degraded and the environment is conserved. In this chapter ICBA work and approach has been comprehensively described with examples of projects implemented around the world in IDB member countries.

Keywords Adversity • Food security • Production system • Site assessment • Soil quality

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3.1 Introduction

Out of three billion people living in rural areas about 2.5 billion are involved in agriculture and 1.5 billion (half of the people in rural areas) are resource-poor smallholders. These make up the majority of farmers (85% farming less than 2 ha) in the developing world (Subhash et al. 2010) and are therefore important in the context of eliminating poverty. In countries as diverse as Bangladesh, China, Egypt, and Malawi, 95% of farms are smaller than 2 ha. Moreover, 75% of poor people live in rural areas. Of these 2.1 billion live on less than 2 US$ a day and 880 million live on less than 1 US$ a day, and most of them depend on agriculture to meet their communities' nutrition and food needs—an imperative for meeting the Millennium Development Goals (MDGs) of halving poverty and hunger by 2015 (Subhash et al. 2010). In 2005, nearly half of the economically active population in developing countries (2.5 billion) relied on agriculture for their livelihoods (IFPRI 2009). Poor smallholders face a number of challenges, including meeting increasing food demand for their ever-increasing families and livestock, achieving health and nutrition security, improving production systems and livestock to increase their income, environmental protection, education, and extension. In the past five decades the world population has increased significantly, while the amount of land devoted to arable agriculture globally has increased only by about 9% (Pretty 2008). Even the Green Revolution that improved crop production—especially in Asia—has now waned, experiencing stagnation or slowdown in agricultural production and damage to the environment due to the high use of inputs over the past two decades. The reasons for this include poor understanding of the problem, financial constraints, limited accessibility of modern technologies, and degraded soil and water resources quality. Additionally, the competition between land uses for agriculture, energy, and other human activities makes a further "Green Revolution" an increasingly unlikely and costly solution, particularly if higher priority is given to protecting biodiversity and the public goods provided by natural ecosystems (for example carbon storage/sequestration in rainforests) (Balmford et al. 2005).

Owing to the challenges of soil and water salinity, soil erosion, desertification, and unsustainable land management, many farmers have set aside marginal lands and abandoned agriculture. Further losses that may be exacerbated by climate change are likely (IPCC 2007). Thus the more probable option is to produce more food from the same good agricultural land and to exploit the abandoned marginal lands; however, this requires sustainable intensification. Another realistic approach could be narrowing the yield gap (the difference between the realized productivity and the best that can be achieved using current genetic material, available technologies in soil and water conservation, and other management tools) between developed and developing countries. It has been observed that there is a wide geographic variation in crop productivity. Farmers in the poor world can achieve good productivity and narrow the yield gap if they are aware of recent developments in agricultural technologies, but this is only possible when the research/extension component is highly linked with and devoted to reach the end user, i.e., the farmer. Farmers' timely access to good quality seeds, water, nutrients, pest management, soil and water management, and the latest knowledge and guidance can increase crop production. Recent studies suggest that the world will need 70–100% more food by 2050 (World Bank 2008; Royal Society London 2009).

In the context of projected population growth and improving incomes, it is estimated that by 2050 agricultural demand will range 50–80% above today's level of production (Müller 2009; FAO 2006a). However, the environmental cost associated with increased food production may rise with globalization, for example because of increased greenhouse gas (GHG) emissions, especially nitrous oxides and methane which are relatively more damaging than CO_2 and for which agriculture is the major source (Stern 2007). The emissions of GHG from agriculture are mostly related to three main activities. These are: (1) CO_2 emissions from fertilizers (urea and ammonium bicarbonates), land conversion to cropping, use of agricultural machinery and livestock production; (2) nitrous oxide (N_2O) emissions from nitrogen fertilizers, manures and nitrogen-fixing legumes, as well as microbial conversion of other nitrogen sources in agricultural soils; and (3) methane emissions from livestock and irrigated rice production. The livestock industry produces about 7.1 billion t of CO_2 equivalents, which represents 18% of the total anthropogenic GHG emissions. Relative contributions along the food chain are 36% land use and land use change, 7% feed production, 25% animals, 31% manure management, and 15% processing and transport (Gerber and Steinfeld 2008). The GHG emissions from livestock rearing are mainly methane emissions from enteric fermentation, animal manures, and respiration.

To maintain and improve the livestock industry and to cope with the associated GHG emissions, biotechnology is an area which may support plant production for animal feed with modified composition that increases the efficiency of meat production and at the same time reduces methane production. According to recent FAO estimates, the livestock industry is responsible for 18% of the total anthropogenic greenhouse gases. The GHG contribution from the livestock industry would be reduced by vegetarian diets. This is supported by the fact that the conversion efficiency of plants into animal matter is approximately 10% and thus there is a prima facie case that more people could be fed from the same amount of land if they were vegetarian, as a third of global cereal production is currently being fed to animals (FAO 2006b). In reality the trend is opposite, as in the past five decades, due to rapidly increasing meat and dairy consumption the number of animals (cattle, sheep, and goats) increased approximately 1.5-fold, with equivalent increases of ~2.5 and 4.5-fold for pigs and chickens respectively (FAOSTAT 2009). In many developing countries meat represents a concentrated source of vitamins and minerals, which is important for individuals such as young children. Other benefits of animals are their use in ploughing (farm activities) and the use of manure for agricultural activities, with the latter being able to partially offset the use of chemical fertilizers (FAO 2003).

According to the agricultural chapter of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), direct agricultural emissions made up 10–12% of the total anthropogenic GHG emissions (5.1–6.2 Pg CO_2-eq) in 2005 (Smith et al. 2007). The GHG emissions from deforestation, mainly in tropical countries, contributed an additional 5.9 Pg CO_2-eq per year (with an uncertainty range of +2.9 Pg CO_2-eq), thus equaling or exceeding emissions from all other agricultural resources combined (Maene and Doumbouya 2009), deforestation and land-use change (12%), and fertilizer (2–3% breaking down into fertilizer production 0.93%, fertilizer distribution 0.07% and fertilizer use 1.5%). From the current situation and the increasing food demand it is apparent that GHG emissions will continue to rise unless significant measures are taken for efficient and responsible food production and environmental protection. At the University of Copenhagen's Agriculture and Rural Development Day on 12 December 2009 several speakers said that agriculture is 7% of the GHG problem, but represents 20% of the solution (IFA 2010).

Rather than letting farmers wring their hands in despair over the above problems (which limit agricultural production and subsequent food security from good as well as marginal saline lands and livestock), the Jeddah-based Islamic Development Bank (IDB), in partnership with the UAE Government, established the International Center for Biosaline Agriculture (ICBA) in Dubai in 1999. Since its inception, ICBA has been turning adversity into an advantage by providing technical support to poor farmers in the Islamic world. It has done this through the National Agricultural Research Systems (NARS) of various countries, by improving soil quality and providing production systems for better agricultural services from marginal/saline lands and water resources. This paper describes the history of ICBA, its geographic coverage, its network in the Islamic world, and the nature of the work it has completed. It also highlights the services provided to different countries in improving soil quality and introducing alternative production systems for better food security.

3.2 ICBA—History

The ICBA was the result of a strategic decision taken in the early 1990s to build a research and development institute focusing on the problems of soil and water salinity and the use of saline water for irrigated agriculture. The IDB with support from the UAE Government, the Kuwait-based Arab Fund for Economic and Social Development (AFESD), the OPEC Fund for International Development (OFID), the International Fund for Agricultural Development (IFAD), and the Municipality of Dubai established the center with world-class modern research facilities to conduct research on improving water resources and the well-being of poor farmers (ICBA 2000) who cultivate crops in marginal lands using saline water (biosaline agriculture). In 2008, ICBA re-examined its strategic plan (ICBA 2008), which involved extended stakeholder consultations and background studies. It concluded that ICBA has to take on a wider range of water issues to deliver even more value to its stakeholders.

3.3 Problem Perception and Solution

Of 13.28 billion ha worldwide, forests and woodland occupy 29.3% (3.89 billion ha), arable land 10.8% (1.44 billion ha), permanent meadows and pastures 25.3% (3.3 billion ha), and other lands 32.7% (4.35 billion ha). Other lands have the potential for agricultural expansion in marginal and saline lands. Planet Earth has a land surface of about 13.2×10^9 ha. Of this total land only 7×10^9 ha are arable, a mere 1.5×10^9 ha of which are cultivated (Massoud 1981). Of the cultivated lands, about 0.34×10^9 ha (23%) are saline and another 0.56×10^9 (37%) are sodic. An older estimate (Szabolcs 1989) presents 10% of the total arable land as being affected by salinity and sodicity, extending to over more than 100 countries and almost all continents.

In sub-Saharan Africa (SSA), particularly the Sahel, and in South Asia (SA), a high proportion of lands are characterized as marginal, and therefore agriculture is currently not viable there. Significantly, lands that have been irrigated for generations have become so affected by salinity that farmers have abandoned them. ICBA scientists strongly believe that such types of land have the potential to become productive if appropriate salt-tolerant crops, soil and water conservation technologies, and improved farming systems are introduced. This is the essence of *biosaline agriculture*. The farmers of SSA and SA face a daunting challenge in meeting increasing demands for both sufficient water quality and quantity for their families, their livestock, and their agricultural needs. In SSA, the combination of historical crop production and weather data into a panel analysis predicted a yield decline for maize, sorghum, millet, groundnut, and cassava by 22, 17, 17, 18 and 8% respectively by 2050 (Schlenker and Lobell 2010). High temperatures and low rainfall in many countries have led to an overall loss of surface water through evaporation. Less obvious, but perhaps more ominous, is what happens beneath the surface. Reduced surface water means less recharge of aquifers, and as demand for water increases, groundwater reserves are over-exploited. In coastal areas, the situation is exacerbated by seawater intrusion. The end result is that over the years, the salinity of groundwater has increased sharply. In many areas, salinity levels in inland aquifers are greater than 15,000 ppm and thus limit crop selection for irrigated agriculture. At this range only salt tolerant crops can be grown (biosaline agriculture). In coastal areas salinity levels are often as high as 25,000–30,000 ppm.

In collaboration with scientists from various countries' National Agricultural Research Systems (NARS) and policymakers, ICBA is turning adversity into an advantage by providing technical support in soil and water conservation and improvement, and by introducing alternative production systems using saline soil and water resources. ICBA's efforts to identify forage species that can thrive in saline conditions have been highly successful. The technical support given to NARS in soil reclamation brought the salt-affected lands to profitable and economical agriculture. In most cases, both soil and water are too salty for conventional crop species. However, they are perfectly viable for growing a number of useful salt-tolerant forage species. These practices range from carrying out an initial soil assessment to gain a better understanding of soil resource quality, to establishing a site-specific soil management plan (site preparation, use of soil amendments, excess salt leaching, salinity mapping and monitoring, nutrient management, and other cultural practices). The initial plan helps farmers to take necessary actions to improve and maintain soil health in general and root-zone salinity in particular during the course of crop growth, and to ensure that soil quality is not degraded and the environment is conserved. In this way farmers can earn good earnings through improving soil health for future agriculture. We believe that if the incomes and livelihoods of poor farming families can be improved, everybody wins. Another interesting area to sustain food security is the use of precision agriculture, which refers to the use of a series of technologies that allow the application of water, nutrients, and pesticides only to the places and at the time they are required, thereby optimizing the use of inputs (Day et al. 2008). However, this requires investigation and investment for its implementation.

3.4 Turning Adversity into an Advantage

ICBA scientists believe that if farmers in the target areas are up against staggering difficulties, and continue to raise conventional crops in their saline soils, their future is bleak. But if forage crops are introduced that not only tolerate but thrive in saline conditions, the whole picture changes for the poor farmers, leading to improved food security and perhaps combating the effects of climate change. Conventional crops are generally not salt-tolerant compared with forages, and most forage production systems consume large amounts of fresh water per unit of dry matter produced. Moreover, forage production is often insufficient to meet the demands of an increasing livestock population, which leads to increasing pressure on natural rangeland resources and contributes to land degradation and desertification. Therefore the development of production systems that use saline water in salt-affected environments addresses several important economic and environmental constraints.

The main challenge of using saline and brackish water in agricultural production is to develop sustainable and economical production systems for each target area through this set of parameters: selecting appropriate plant species; identifying saline and brackish water resources; identifying available land resources for the application of biosaline agriculture; developing appropriate soil salinity management practices; developing irrigation and leaching practices that can maintain root-zone salinity at acceptable levels; evaluating applicable forage production systems; and monitoring livestock production. The objective of such work is to enable poor farmers in partner countries to improve their soil resources for better production and to nourish their livestock by adopting salt-tolerant forage varieties and agronomic practices designed for use on marginal lands. The capacity to raise healthy animals by feeding them with forage crops, grasses, shrubs, and trees that can be sustained indefinitely on saline and marginal lands will result in increased incomes and improved livelihoods, and sustain food security. In the above perspectives ICBA undertook several studies through the introduction, selection, and identification of new forage species in targeted salt-affected areas in partner countries. Germplasm was selected based on prevailing climatic, soil, and water conditions. After potential germplasm was identified, appropriate agronomic practices such as establishment methods, fertilizer requirements, and irrigation techniques were introduced to optimize productivity.

The development of a sustainable production system essentially requires the work to be conducted in a systematic and integrated way through soil and water assessment of the target areas in partner countries; acquisition of potential domestic and exotic germplasm (Fig. 3.1b); screening and evaluation of germplasm and

Fig. 3.1 ICBA and turning adversity into an advantage. **a** Water pump—saline water source (ICBA). **b** Salt-tolerant species—Genebank (ICBA). **c** Sultanate of Oman (capacity building). **d** Samarkand (capacity building). **e** Highly saline abandoned land. **f** Turning adversity into advantage

selection of potential species; preparation of field and irrigation systems; selection of agronomic practices; assessment of the biomass productivity of different species/accessions at various growth periods; and evaluation of the nutritive value of forage for livestock. In the introduction of such packages the role of ICBA has been to guide and coordinate the activities in each partner country. However, the implementation was carried out through national programs and farmer groups by using a participatory approach on farmers' and NARS fields. The plant production packages were introduced and tested at a range of locations representative of salinity problems in participating countries.

Another important component is capacity building for the national programs, particularly for extension staff and farmers. This component includes training courses and workshops as well as internships for representatives of the partner countries. Annual meetings and field days were rotated among the partner countries to provide the opportunity for key representatives to familiarize themselves with the progress of their peers in other countries. ICBA was responsible for fully involving all collaborators and ensuring that all activities and outputs were completed satisfactorily and adhered to the projects' technical scope of work. At ICBA and in partner countries a number of specialized training courses have been conducted to provide technical support and build the capacity of professionals and farmers in partner countries (Oman, the UAE, Kuwait, Libya, Morocco, Niger, Jordan, Samarkand, and Syria) in order to improve agricultural activities and to help fight food insecurity. Over the period 2000–2008 ICBA trained 947 participants from 44 IDB member countries.

3.5 Geographic Coverage

Since ICBA's inception, its geographic scope has been growing and, as it matures, the ICBA focuses on the acutely water-scarce countries of the Middle East and North Africa (MENA) region (including the Sahel), West Asia and North Africa (WANA), and Central Asia and the Caucasus (CAC). It is also expanding to include sub-Saharan Africa (SSA). As time progresses and opportunities emerge, the effort will continue to expand into other regions. To date ICBA has been working with many countries (Fig. 3.2), either implementing projects through their respective NARS, or helping them develop capacity building for their manpower (Fig. 3.1c, d).

3.6 ICBA—Experimental Station and Resources

The Dubai Municipality designated 100 ha of land in Dubai Academic City. Of 100 ha, 35 ha divided into 14 blocks of 2.5 ha each have been allocated to conduct research. The rest of the 65-ha hummocky sandy area is used for the protection and rehabilitation of natural ecosystems common in the area. The experimental site is generally level, loose sand, very deep and calcareous, with a very high drainage ca-

Fig. 3.2 Geographic coverage of ICBA partner countries

pacity (well to somewhat excessively drained), and soils are moderately to rapidly permeable. The dominant soil type is carbonatic, hyperthermic Typic Torripsamment (USDA-NRCS 1999, 2010). Where carbonatic is the mineralogy class, i.e., more than 40% $CaCO_3$ in the control section, hyperthermic is the soil temperature regime (the mean annual soil temperature is 22°C or higher, and the difference between mean summer and mean winter soil temperature is more than 6°C at a depth of 50 cm from the soil surface). Typic Torripsamment indicates typical desert sandy soil at the soil subgroup level of the USDA Soil Taxonomy. In places soils with well-developed calcic horizon are also identified (Typic Haplocalcids); however, these soils occur to a minor extent. In general, the water table fluctuates within 2–3 m, in some places within 1–2 m with seasonal fluctuation. The surface soil texture is fine sand (sand 98%; silt 1%; clay 1%). Among sand subfractions fine and very fine sand accounts for 78% of total sand. The native soil is nonsaline (ECe less than 4 dS m^{-1}), moderately alkaline (pHs 8.22) and strongly calcareous, and very low in organic matter content (<0.5%). The torripsamments are representative of typical desert sandy soils and hence technologies established at the ICBA experimental station have wider applications and acceptance worldwide, especially where torripsamments are the main soil types.

In Abu Dhabi Emirate, which covers 84% of the total UAE area, torripsamments are the dominant soils and occupy 81% of the total area (EAD 2009a; Shahid 2006; Abdelfattah and Shahid 2007; Shahid and Abdelfattah 2008); In Kuwait torripsamments occupy 27% of the total area (KISR 1999; Omar et al. 2001). There is one water source at the ICBA station (Fig. 3.1a) that is saline and sodic [(EC 30 dS m^{-1} and SAR 31 $(mmoles/l)^{0.5}$] and the quality fluctuates slightly (25–30 dS m^{-1}) with aquifer recharge after heavy rain. The importance of these parameters in relation to water quality for irrigated agriculture is discussed by Shahid (2004). The water

Table 3.1 ICBA target water salinity levels

Salinity classification	EC (salinity) range	Production system
Slightly saline	<5 dS m^{-1}	Glycophytes
Moderately saline	5–15 dS m^{-1}	Salt tolerant/glycophytes crops
Highly saline	15–25 dS m^{-1}	Salt tolerant/glycophytes and halophytes crops
Very highly saline	>25 dS m^{-1}	Halophytes crops
Sea water	40–60 dS m^{-1}	Halophytes crops

quality class (Richards 1954) is C4S4 (C4 very high-salinity, S4 very high sodium). Low-salinity water (EC = 2–3 dS m^{-1}, i.e., 1,400–2,100 ppm) is provided by the Dubai Electricity and Water Authority (DEWA) from the Dubai-Al-Ain area at Habab. The two water sources are combined in mixing chambers located at the start of each strip in each experimental block to establish different water salinity levels to match experimental requirements. The groundwater salinity at the center is much below that of sea water; therefore, in the experiments where sea water is required for irrigation (Nypa grass, salicornia), the sea water is brought to the center via water tankers and stored in tanks for irrigation.

3.7 Targeted Water Salinity Ranges

Table 3.1 shows water salinity ranges on which ICBA has been focusing since its inception. The major focus is water salinity above 5 dS m^{-1}. At water salinity below 5 dS m^{-1} many conventional crops (glycophytes) can be grown using standard soil, water and nutrients.

3.8 Basic Concept of Salinity Tolerance, Relative Crop Prediction and Root Zone Salinity Management

Crops can tolerate salinity up to certain levels without a measurable loss in yield (this is called the threshold level). As a general rule, the more salt-tolerant the crop, the higher the threshold level. At salinity levels greater than the threshold, crop yield reduces proportionally as salinity increases. Using the salinity values in the salinity/yield model developed by Maas and Hoffman in 1977, predictions of expected yield loss can be made. Maas and Hoffman expressed the salt tolerance of crops by the following relationship,

$$Yr = 100 - s(ECe - t),$$

where Yr = percentage of the yield of crop grown in saline conditions relative to that obtained in nonsaline conditions; t = threshold salinity level where yield decrease begins; s = percentage yield loss per increase of 1 ECe (dS m^{-1}) in excess

Table 3.2 General threshold (*t*) and slope (*s*) values to calculate crop yield as a function of soil salinity (*ECe*) for various crops. (Hoffman 2001)

Crops	Threshold (*t*) *ECe* dS m^{-1}	Slope (*s*) % yield loss per 1 *ECe* (dS m^{-1}) above (*t*)
Alfalfa (*Medicago sativa*)	2.0	7.3
Barley for grain (*Hordeum vulgare*)	8.0	5.0
Bean (*Phaseolus vulgaris*)	1.0	18.9
Bean, dry edible (*Phaseolus vulgaris*)	1.0	19.0
Cabbage (*Brassica oleracea*)	1.8	9.7
Carrot (*Daucus carota*)	1.0	14.1
Clover (*Trifolium spp.*)	1.5	12.0
Corn for grain (*Zea mays*)	1.7	12.0
Corn for silage (*Zea mays*)	1.8	7.4
Cucumber (*Cucumis sativus*)	2.5	13.0
Date (*Phoenix dactylifera*)	4.0	3.6
Lettuce (*Latuca sativa*)	1.3	13.0
Onion (*Allium cepa*)	1.2	16.1
Pepper (*Capsicum annum*)	1.5	14.1
Potato (*Salanum tuberosum*)	1.7	12.0
Radish (*Raphanus sativus*)	1.2	13.0
Sorghum for grain (*Sorghum bicolor*)	6.8	16.0
Soybean (*Glycine max*)	5.0	20.0
Spinach (*Spinacia oleracea*)	2.0	7.6
Sugar beet (*Beta vulgaris*)	7.0	5.9
Tomato (*Lycopersicum esculentum*)	2.5	9.9
Wheat for grain (*Triticum aestivum*)	6.0	7.1

s = % yield loss per 1 ECe (dS m^{-1}) increase above t (ECe) value, *t* = salinity threshold ECe (dS m^{-1}), where yield is optimum

of *t*. Salinity mapping at the farm level and Table 3.2 may be used as a general guide to predict yield losses. It is essential to manage root-zone salinity to ensure it does not increase above the plant's threshold level (*t*). This requires regular salinity monitoring throughout the cropping season. A number of techniques (Shahid 2005; Shahid et al. 2010) exist to measure field soil salinity (such as salinity sensors and electromagnetic devices); however, for many reasons, laboratory analysis of soil saturation extract is still the most common technique for assessing soil salinity and other potential hazards, because the amount of water that a soil holds at saturation (saturation percentage) is related to a number of soil parameters such as texture, surface area, clay content, and cation-exchange capacity. If sufficient resources are available, then the farmer may have a choice in selecting the technique, depending upon the purpose of salinity determination, the size of the area being evaluated, the depth of the soil to be assessed, the number and frequency of measurements needed, the accuracy required and the availability of resources. Regardless of the technique, the objective is to monitor salinity in the root zones to help take action to keep the root-zone salinity below the plant's threshold.

3.9 Turning Adversity into an Advantage—Developing a Resource Base at ICBA

For a research center focusing its work on salinity issues, it is essential to start by gathering salt-tolerant germplasm, a basic resource required for biosaline agriculture research. In this regard, since ICBA's inception in 1999, its continuing efforts have created a Genebank (at a controlled environment of 5–7°C and 30–40% relative humidity) through assembling the germplasm of species with proven or potential salinity tolerance to provide a source of genetic diversity to mitigate salinity problems in agricultural production systems (Fig. 3.1b). To date, the number of accessions to the genebank has increased to 9,418 from 251 species in 134 countries. Significant efforts are being made to multiply new germplasm accessions and seed conservation, trials, nurseries, and distribution. The ICBA genebank has been used for in-house as well as for outreach projects in the UAE and in partner countries. To date, ICBA has provided 423 seed samples to partner countries.

At the ICBA station a production system has been developed and management practices have been optimized for two salt-tolerant grasses (*Sporobolous virginicus* and *Distichlish spicata*) by using three levels of saline water (10, 20 and 30 dS m^{-1}), three ET levels (low ETo, medium 1.5ET and high 2ET) and four fertility levels (0-0-0, 20:10:10:, 40:20:20: and 60:30:30 units of NPK ha^{-1}). The irrigation is done using sprinklers, with 3–4 cuts per annum, and a production of 30–35 t dry matter ha^{-1} is achieved. Their nutritional value is similar to that of the widely grown Rhodes grass in the UAE and their mineral content is within international standards for forage quality (ICBA 2007a). An alternative production system demonstrated at the ICBA experimental station is the saltbush "Atriplex" (ICBA 2007b) irrigated (drip) with three water salinity levels (10, 20 and 30 dS m^{-1}) with a production level ranging from 13.9 to 24.1 t ha^{-1} green matter. Saltbush is generally constituted of 10% leaf, 20% thicker stems, and 70% branches; the leaves contain up to 20% salt, and thicker stems and branches provide no metabolic energy. However, the pastures should provide energy, proteins, and low salt contents, which is not the case with saltbush. The normal metabolic energy required is 8 MJ kg^{-1}; saltbush provides 7 MJ kg^{-1}. The required rate of crude proteins is 8% of dry weight; salt bush provides 13% of dry weight. The threshold salt level is 15%; Atriplex generally contains 22.5% salts on a dry weight basis. This suggests the compensation of energy to be made through other sources; therefore a balanced mix of hay with saltbush may resolve the issue of grazing in saline lands. Feeding Atriplex alone can cause weight loss in animals and lower milk production. This is a compromise on lands where conventional forages cannot be grown. Another important production system is the date palm, which is commonly grown in Gulf Cooperation Council (GCC) countries of the Arabian Peninsula and plays an important role in the national economies, history, and culture. Of the total cultivated area for date palms (more than 1 million ha), 60% exists in the Arab world. Of 6.4 million t produced globally, a 63% contribution is from the Arab world, with GCC countries contributing 29% of global production. Owing to the importance of the date palm in the region, since

2001 ICBA has been conducting salt tolerance experiments on elite date palm varieties from the UAE and Saudi Arabia. The findings will help GCC countries to take benefits from this investigation and to grow date palms using saline water.

Another focus of ICBA work is on screening salt-tolerant forages like barley (*hordeum vulgare*), buffel grass (*Cenchrus ciliaris*), fodder beet and fodder rape/brassica varieties, safflower, pearl millet, sorghum, sesbania, and cowpea. One major focus is on pearl millet and sorghum as forage. Screening experiments allowed the selection of potential genotypes for field evaluation. To date, more that 300 genotypes of pearl millet and 306 genotypes of sorghum, 2,300 accessions and varieties of barley, 950 accessions of triticale, 100 accessions of sunflower, 65 species/varieties and accessions of sesbania have been evaluated at ICBA at 5, 10 and 15 dS m^{-1} water salinity levels. Promising genotypes were evaluated in the field, and seeds multiplied and distributed to collaborating NARS. An integrated agroforestry approach (ICBA 2007c) has been tested using *acacia ampliceps*, *sporobolus arabicus*, and *paspalum vaginatum* at different salinity levels. *Acacia ampliceps* is a salt-tolerant tree which fixes atmospheric nitrogen and can be used as forage or as a source of bioenergy. The integration of *acacia ampliceps* with grasses proved helpful in grass nutrition through the acacia rooting system. The findings of this study may optimize nutrient cost and help combat greenhouse gases (GHG) produced through nitrogenous fertilizer manufacture and its use in pastures for livestock production. The livestock industry solely contributes 18% of the total methane (CH_4) emissions.

Research at ICBA has shown that field crops such as asparagus, sunflower, mustard, guar, sesbania, cowpea, pigeon pea, and quinoa have good adaptation in the UAE environment. Many of these crops are drought-tolerant with low water requirements and have more than one use as seeds, forage, oil, and vegetables. Therefore they have excellent potential to provide high economic returns to the farmers; however, care must be exercised to manage root-zone salinity during the cropping season. The ICBA hosts a world-class Central Analytical Laboratory (CAL) and an auditorium. The CAL provides independent services for in-house projects and external agencies.

3.10 Turning Adversity into an Advantage Around the World

Of 57 Islamic member countries of the IDB, ICBA has jointly completed research and development applied projects in over 20 countries, and has built capacity for over 900 participants from 44 IDB member countries. The summary of such collaborative ICBA work with partner countries is briefly described here. The Middle East, North Africa, the Sahel, and the Central Region are the most water-scarce areas on the Earth. The rural poor suffer the most from water scarcity, because they lack political or economic influence and the financial resources to buy water services. When water supplies, sanitation, or irrigation services fail to reach them, their livelihoods and health are seriously compromised. The following section provides a summary of some key projects ICBA has completed jointly with NARS, according to the concept of "turning adversity into an advantage." The focus has been on Central Asia and the Caucasus (CAC), West Asia and North Africa (WANA), South Asia and Africa. The international projects jointly completed by ICBA with NARS are shown in Table 3.3 with target water salinity levels. A project jointly funded by IFAD, OFID, and AFESD was implemented by ICBA in seven countries (Jordan,

Table 3.3 Some completed projects worldwide

Project title	Participating countries	Donors	Water EC (salinity) target
Forage project for the WANA region	Jordan, Oman, Pakistan, Palestine, Syria, Tunisia, and UAE	IFAD, AFESD, OFID	Saline/brackish ground water 10–25 dS m^{-1}
Sorghum and pearl millet for enhanced crop livestock productivity	Egypt, Iran, Oman, Tunisia, Yameb	OFID	Saline/brackish ground water 10–25 dS m^{-1}
Biosaline Forestry (BIOSFOR)—biomass for bioenergy	Bangladesh, India, Pakistan, Netherlands, Spain, Germany, UK	European Union	Saline/brackish ground water 15–25 dS m^{-1}
Bright spots in Aral seas	Uzbekistan, Kazakhstan, Turkmenistan	Asian Development Bank	Saline/brackish ground water 15–30 dS m^{-1}
Harnessing productivity in salt-affected soils of the Indo-Gangetic, Mekong, and Nile river basins	Iraq, Egypt, Philippines	CGIAR Challenge Program	Saline/brackish ground water 10–25 dS m^{-1}
Biosaline agriculture at National Prawn Company, Kingdom of Saudi Arabia	Kingdom of Saudi Arabia	National Prawn Company	Sea water and brackish water 25–40 dS m^{-1}
Salt-tolerant forage production systems in the Sinai Peninsula	Egypt	ICBA and Desert Research Center Egypt (bilateral project)	Saline/brackish ground water 10–25 dS m^{-1}
Production of halophytes in Iran	Iran	ICBA and National Salinity Research Center (bilateral project)	Saline/brackish ground water 10–25 dS m^{-1}
Identifying new sources of income for poor farmers in Bangladesh	Bangladesh	ICBA and Bangladesh Agriculture Research Institute (bilateral project)	Saline/brackish ground water 10–25 dS m^{-1}
Reclaiming salt-affected farms in Tajikistan	Tajikistan	ICBA and Tajik Academy of Agricultural Sciences (bilateral project)	Saline/brackish ground water 10–25 dS m^{-1}
Brine disposal from Reverse Osmosis Units	UAE	ICBA and Ministry of Environment and Water	Saline/brackish groundwater 25–40 dS m^{-1}

Oman, Pakistan, Palestine, Syria, Tunisia, and the United Arab Emirates). The major focus of the project was the introduction of salt-tolerant forage production systems (pearl millet, sorghum, mustard, barley, fodder beet, grasses, etc.) for under-utilized saline lands and poor quality water; saving fresh water resources and improving livelihoods; seed multiplication of key species for scaling up; and extensive capacity building for the project staff and the farmers, including field and farmer days. The production systems were introduced to farmers' fields through demonstration plots (ICBA 2007d). More than 120 farmers participated in the project.

Given the adaptability displayed by the farmers in the face of post-climate change variability (Adger and Agrawala 2007), African farmers will likely continue to adapt as the climate changes—for example by adopting new crops or varieties or by altering the timings of planting and other agronomic practices. But if future climates move as quickly outside the range of past experience as they are expected to throughout the tropics (Battisti and Naylor 2009), farmers may be unable to adapt rapidly enough without some help. As a result, there exists a widely acknowledged need for significant investment in agricultural adaptation, but there has been little systematic assessment of how to prioritize this so-called planned adaptation—what form it should take, and what crops and locations it should focus on (Burke et al. 2009).

Owing to the importance of climate change on agriculture and following the success of the IFAD-funded forage project, a grant of 2.4 million US$ has been granted to ICBA for adaptation to climate change in marginal environments through diversification of forage/livestock systems. What is required under such projects is a new paradigm of greenhouse gas-efficient farming and general land management that provides good forages for livestock and, at the same time, increases carbon storage in soil, especially through adopting conservation tillage or perhaps zero tillage, which not only conserves energy but also enhances soil productivity and can relieve pressure on marginal land and maintain ecosystem function and biodiversity. The project will be implemented in the WANA region over four years (2010–2013), where different forage production systems which have already been tested at the ICBA experimental station and in the WANA region will be upscaled to many farmer fields to help improve their livelihoods and livestock production, thus leading to better food security.

Central Asia and the Caucasus (CAC) suffer from land degradation due mainly to mismanagement of irrigation and drainage. This leads to a loss of areas under cultivation (cotton), which calls for immediate action to be taken to reclaim these areas, as well as the introduction of alternative production systems appropriate for current soil and water conditions. ICBA, the International Water Management Institute (IWMI), and the International Center for Agricultural Research in the Dry Areas (ICARDA) jointly implemented a project (ICBA 2007e) in Kazakhstan, Turkmenistan, and Uzbekistan. The objective was to improve the irrigation systems, increase agricultural productivity, improve soil and nutrient management, improve agronomic practices, and strengthen institutions. The overall goal of the project was to address poverty alleviation, improve food security at the household level, and improve environmental security through the development, promotion, and adoption of strategies that enhance the productivity of existing irrigated farming systems in Central Asia.

In the Middle East and North Africa (MENA) region, support has been provided to Egypt, Jordan, Oman, Palestine, Syria, Tunisia, the UAE, and Yemen for the improvement of forage for livestock and salt-tolerant crops and the development of sustainable production systems. Conventional forage crops such as sorghum, pearl millet and fodder beet, Atriplex spp. and Acacia ampliceps have proved very successful. In Bangladesh (ICBA 2007f), ICBA helped farmers of the coastal area to grow cash crops (tomato, chili, watermelon, and cucumber) on land traditionally left fallow after rice cultivation. During the dry months the coastal lands are severely salinized through sea water intrusion. Water management through raised beds with a drip irrigation technique, mulching, and leaching salts significantly improved yields and livelihoods.

In the host country, the UAE, joint projects and technical support have been provided in: (1) completing a scientific inventory of soil resources for decision-making, rational uses of soil resources, and informed land use planning (EAD 2009a; ICBA-EAD 2010); (2) carrying out a waste water assessment and use plan (EAD 2010); (3) introducing biosaline agriculture (ICBA 2007g); (4) undertaking a soil resource assessment on Sir Bani Yas as part of the Desert Islands Project (ICBA-TDIC 2008); (5) reclaiming degraded forestry farms; (6) creating laboratory analytical services; and (7) capacity-building of UAE nationals. Jointly with EAD, ICBA recently prepared the Abu Dhabi Water Master Plan (EAD 2009b). The objective was to develop a clear strategy for managing the water sector and to balance consumption between agricultural, industrial, and domestic sectors for the sustainable economic development of the Emirate. The specific objectives were to develop: (1) clear goals and strategies to promote institutional performance in the water sector; (2) policies in the water sector; (3) policies, rules, and standards; (4) plans for capacity-building, public awareness, and upgrading information system services; and (5) a work plan for targeted projects and their costs.

In the Sultanate of Oman ICBA has implemented a number of projects in collaboration with SQU Oman and the Ministry of Agriculture (MoA), Oman. A joint project with SQU on the "management of salt-affected soils and water for sustainable agriculture" was completed over a period of three years (2006–2009). The results are documented in a monograph (ICBA-SQU 2007; Mushtaque et al. 2010). In 2010 ICBA started a project jointly with the Ministry of Agriculture in Oman to develop a national strategy aiming at conserving water resources from pollution and salinization (ICBA-MoA 2010). A strategic plan for salinity management in Iraq has been started jointly by the Australian Center for International Agricultural Research (ACIAR), ICARDA, IWMI, ICBA, and CSIRO, Australia.

3.11 ICBA Recommends an Integrated Approach for Soil Management and Reclamation

Improvement of root-zone soil quality requires careful management of irrigated agricultural fields. The main objective is to increase the yield per unit area, to increase the water and fertilizer use efficiency, and to improve the farmers' livelihoods. Efficient, effective and long-term soil quality improvement requires the use of an integrated approach including physical, chemical, hydrological, and biological methods specific to the site's conditions. Therefore, based on the site's characteristics, a combination of the following methods is to be used for effective soil management in production systems:

Physical methods include leveling of the site, salts scraping, deep ploughing and tillage, subsoiling and sanding as appropriate. Leveling (preferably laser leveling) is essential for uniform distribution of water for leaching or flushing. Where salt crusts appear on the surface it is feasible to scrape salts mechanically. Low salinity in the root zone can be achieved through tillage practices by manipulating the soil surface condition, i.e., bed shape and irrigation management. It is very well recognized that salts tend to accumulate on the ridges away from the wet zone when furrow irrigation is adopted (Fig. 3.1e). Placing the seeds on the off-center slope of a single row will put the seed in minimum salinity and optimum moisture conditions (Fig. 3.1f). Subsoiling is particularly important for disrupting the dense layers deep in the soil to enhance permeability.

Hydrological methods are concerned with water use and drainage. The root-zone salinity may increase if the net downward movement of salts is less than the salt input from irrigation, and salt water fluxes to the surface. Traditionally, saline soils have been reclaimed by flooding or by ponding water. In general, the depth of soil leached is roughly equal to the depth of water infiltrated during leaching. In order to leach the salts, the leaching requirement (LR) is very important. The recent trend is to minimize LR in order to prevent the groundwater from rising and to minimize pressure on the drainage system (Mashali 1995). Methods to calculate LR and to predict the losses in yield due to salinity are described by Rhoades (1995). Timely leaching is important to assure root-zone salinity is not exceeded above the crop salinity tolerance limit for extended periods of time or at critical stages of plant growth. Leaching can be done: when soil moisture is low and the water table is deep; before the critical growing stage; at low evapotranspiration demand; at night, during high humidity, in cooler weather; and at the end of the cropping season, as appropriate to the area. Drainage lowers the water table, provides adequate leaching, minimizes upward water flux, and thus controls salinity build-up. Modern irrigation methods (sprinklers, drips, sprayers, and subsurface systems) improve water use efficiency; however, each irrigation system develops salinity at a specific soil zone that is to be carefully monitored.

Chemical methods are used to reclaim sodic soils. To have successful crops on sodic soils, the exchangeable sodium percentage of the soil must be below threshold (<15). The main aim is to increase the concentration of calcium in the soil. The long-term objective is to replace exchangeable sodium (ES) with calcium, and use organic matter to bind the soil and improve its structure. Gypsum ($CaSO_4.2H_2O$) is a commonly used amendment (to supply Ca) to rectify sodicity problems in irrigated fields. The gypsum requirement concept is to be used for the reclamation of sodic soils. Experience shows that sodicity is the major problem in Pakistan, but the sandy soils of desert environments like the UAE and Kuwait do not present a sodicity hazard. Chemical amendments other than gypsum are hydrochloric and sulfuric acids. These work satisfactorily when the soils are sodic and calcareous, and the acids mobilize Ca from carbonates for reclamation. Adding elemental sulfur may also be useful in reclaiming sodic soils, with the condition that it is properly oxidized and the soils are calcareous. The S may be oxidized through biological oxidation by *Thiobacillus thiooxidans*, but in sodic soils it is very slow process. The final product is H_2SO_4. ICBA scientists believe that chemical reclamation is expensive for subsistence farmers coupled with malpractice in marketing and unavailability of good quality chemical amendments, such as at least 70% pure gypsum (agriculture grade), which is recommended for reclamation. Low quality amendment does not help achieve the reclamation objectives. These chemicals are not often available in the market when needed, and the use of acids (HCl, H_2SO_4) for reclamation poses health risks due to their toxicity. In addition to these, there is an initial high cost for chemical reclamation and maintenance, and draining of salts causes pollution to groundwater and is a time-consuming exercise. An alternative to chemical reclamation is biosaline agriculture (*vegetative bioremediation*), which means economic utilization of salt-affected soils and saline/brackish waters for agricultural purposes. It involves the cultivation of salt-tolerant species of agricultural significance and the adoption of special agronomic practices to improve their productivity under such conditions. Some scientists use the saline agriculture concept, but "biosaline" is much broader in scope and includes manipulation of desert and sea resources for food and fuel (energy) production. Tables for salt tolerance of different crops are reported elsewhere (Maas 1986). In addition to providing alternative production systems, biosaline agriculture also provides an opportunity for vegetative bioremediation. Salt-tolerant plants produce CO_2 in the root zone, which eventually reacts with H_2O to produce carbonic acid (H_2CO_3), which reacts with $CaCO_3$ in the soil and mobilizes Ca to replace Na from the soil exchange complex and hence reduces the exchangeable sodium percentage (ESP). The N-fixing plants produce protons which help in reducing soil ESP. The plants also remove Na from the soil to a significant extent.

3.12 Agriculture, Carbon Sequestration, and Climate Change

Roughly 50% of the carbon photosynthesized by plants is returned to the atmosphere as CO_2 in the process of plant respiration. The rest, which is the carbon assimilated and incorporated in leaves, stems, and roots, is deposited on or within the soil, and therefore agricultural soils represent one of the best sinks for carbon storage in the Earth's ecosystem and have large mitigation potential through their capacity for carbon sequestration (taking more carbon out of the atmosphere and storing it in natural "sinks" on earth) which has strong synergies with sustainable agricultural production systems. Altogether soils contain an estimated 1,700 Gt (billion metric tons) to a depth of 1 m and as much as 2,400 Gt to a depth of 2 m. An estimated additional 560 Gt is contained in the terrestrial biota, i.e., plants and animals (Hillel and Rosenzweig 2009). In contrast, the carbon in the atmosphere is estimated to total 750 Gt. Thus the amount of organic carbon in soils is more than four times the amount of carbon in the terrestrial biota and three times that in the atmosphere (Hillel and Rosenzweig 2009).

The introduction of alternative production systems in marginal or set-aside lands provides additional synergies with the existing agricultural activities and helps carbon sequestration, which ultimately reduces vulnerability to climate change and reduces GHG emissions. Different production systems (forages, shrubs, trees) used in biosaline agriculture have potential to sequester organic carbon ranging from 0.5 to 1.5 Mg ha^{-1} $year^{-1}$. It is estimated that up to 20% of US carbon emissions can be sequestered back into agricultural soils. There are many ways to achieve carbon sequestration through agricultural activities, such as capturing carbon in plant residue and slowing carbon cycles, retaining carbon in crop residue by not tilling the soil. Hillel and Rosenzweig (2009) reported that a conversion to no-till farming has been found to boost carbon storage in soils at rates varying from 0.1 to 0.7 Mg C ha^{-1} $year^{-1}$, reducing bare soil, reducing soil erosion, increasing crop intensity, using cover crops, selecting crop varieties having a high capacity for carbon storage, producing renewable sources of energy (biofuels) derived from agriculturally grown biomass that can be converted to ethanol and biodiesels, absorbing CO_2 from the atmosphere by enhanced photosynthesis and storing a sizeable fraction of the carbon in the soil, increasing nitrogen use efficiency, improving irrigation management, improving forage quality in grazing lands, and reducing overgrazing. The improved practices used on agricultural land can play a role in solving the problem of greenhouse gas build-up at very little cost to the economy. The farmers can benefit in two ways: through continued agriculture on their farms for themselves and their livestock, leading to better food security; and through trading "carbon credits." However, this system is still in its infancy and there is no way to know how much producers can realistically expect to make from selling carbon credits. The amount of carbon that can be sequestered and the amount of emissions that can be reduced through the adoption of different agricultural production systems still require further investigation and research; however, it is well recognized that agriculture plays a great role in carbon sequestration. Over a four-year period (2010–2013) ICBA is going to implement a project (2.4 million US$) in the WANA region on "Adaptation to Climate Change in Marginal Environments through Diversification of Forage/livestock System" (ICBA-IFAD 2010).

3.13 Soil Quality Improvement and Alternative Production Systems—Pakistan Case Study

Pakistan was among the seven partner countries in an IFAD-OFID-AFESD-funded salt-tolerant forage project to save fresh water resources (ICBA 2007d). The Pakistan component was completed in cooperation with two national organizations: the Nuclear Institute for Agriculture and Biology (NIAB), which is situated in Faisalabad, and works under the auspices of the Pakistan Atomic Energy Commission (PAEC) and the Agency for Barani Area Development (ABAD). In this section, NIAB has been selected as a case study to provide information as to how ICBA implemented the project in seven countries and helped poor farmers to improve their livelihoods. ICBA has chosen NIAB due to its international recognition and their links with farmers through the Farmer Participatory Project. NIAB has a saline agriculture research station in Pacca Anna (40 km from NIAB) where research on marginal lands for crop production is being carried out. This is one of the two sites where ICBA conducted the project. The second site was land abandoned by the farmer due to the severe effect of salinity and sodicity. It was a challenge for both ICBA and NIAB scientists to bring back this abandoned piece of land to sustainable and profitable use.

To develop a sustainable production system, it is essential that resource-based soil management practices are formulated and implemented at proper times during the project. This will help diagnose the practicality or impracticality of these management options to assess the sustainability of production systems and develop confidence in the transfer of established technology to other areas where similar conditions and resources may exist. Meetings between ICBA staff (soil and plant experts) and relevant NIAB project staff led to the development of an integrated strategy for soil quality improvement and crop production. It was decided to first make a scientific-based site assessment, establish baseline soil information, and develop a soil improvement package. Especially for agricultural projects, pre- and post-site assessment is essential to understand soil resource capacity in order to help develop a successful soil management and use plan, as well as to assess the impact of the plan on site characteristics to assure that the site health is maintained and not degraded. The potential soil management issues are initial (pre-)site assessment and establishment of baseline soil information, salt leaching/flushing, soil amendment to ameliorate sodicity, use of site-specific soil preparation methods, nutrient application based on their soil and crop requirements, use of organic fertilizers, hardpan breaking, establishment of drainage systems where required, and use of modern irrigation systems.

3.13.1 Assigning World-Recognized Soil Names to Project Sites and Farmers' Awareness

The objective of this activity was to assign a soil name to the site for international correlation using the international classification system; such an establishment inspires confidence to adopt results without conducting long-term experiments on similar soils and environmental conditions, and thus saves precious time and resources. To achieve this objective the project site was investigated using the latest norms and standards of the USDA-NRCS (Soil Survey Division Staff 1993; USDA-NRCS 1999; USDA-NRCS 2006). The systematic approach used includes: (1) farmers' day; (2) farmer and project staff participation in the site assessment; (3) formulation of a soil management strategy; (4) strategy implementation; (5) selection of salt-tolerant crops well-suited to soil and environmental conditions; (6) introduction of salt-tolerant crops.

In order to implement the above systematic approach, NIAB invited famers from many villages to the project site to demonstrate the value of site assessment and show them the technology involved, as well as to share the ICBA experience with the local farming community. On-site discussion includes excavation of a profile to demonstrate in depth soil variability (Shahid et al. 2009). The farmers were briefed about site/soil characteristics in local Urdu language which was easy for them to understand. The site description revealed that the soil was not homogeneous but layered with different properties. The surface 15 cm were highly saline (ECe 64 dS m^{-1}; ESP 42; pHs 8.43); at 15–35 cm was a layer of clay enrichment (49% clay; ECe 9.75 dS m^{-1}; ESP 39.9); the layer from 35–210 cm was a homogeneous layer with an ECe < 7 dS m^{-1} and clay <16%. The most striking soil feature was the surface accumulation of salts and a clay pan at 15–35 cm deep. The site investigation revealed the soil taxonomic name "coarse loamy, mixed, hyperthermic Typic Natrargid." The taxonomic name explains many characteristics such as the soil belonging to the *Aridisol* order as indicated by the formative element "id"; it belongs to the "Argid" suborder because its profile has an argillic horizon (enriched with clay); it also presents a *natric* horizon due to more than 15 ESP in the argillic horizon; *coarse loamy* is its family textural class; *mixed* is its mineralogy class; it has a *hyperthermic* soil temperature regime, in which the mean annual soil temperature is 22°C or higher, and the difference between mean summer and winter soil temperature is more than 6°C at a depth of 50 cm; *Natrargids* is its Great Group name—Argids that have a natric horizon; *Typic Natrargids* is its subgroup name showing that the profile has typical soil properties to qualify as Natrargid.

The farmers confirmed that this was the first time, after having been in the farming business for many years, that it became clear to them that soil may have layered features, which require different management strategies to tackle salinity issues compared to a homogenous soil layer. The latter requires normal leaching to free the root zone from salinity; the former requires salt flushing to remove salts from the root zone. The farmers in the area revealed that they were using leaching, which intensifies the salinity problem through brackish water use, soil impediment (clay pan), and evaporations. Under such circumstances where surface salinity is high, sodicity is a subsurface problem and clay pan exists, the farmers and project staff were briefed about the sequence of the soil management strategy: (1) creating soil bunds around the field to be reclaimed; (2) ponding water and flushing salts to side channels; (3) breaking the clay pan through chiseling or subsoiling; (4) adding gypsum as an amendment to rectify soil sodicity to improve soil physical and chemical properties; (5) preparing seed beds and placing seeds on bed shoulders in an area free of salts. That salt accumulates at the top of the plant bed with furrow irrigation is evident (Fig. 3.1e). The demonstration of this integrated approach was witnessed by the farmers (Fig. 3.1e, f), and therefore developed their confidence to use site-specific soil management recommendation.

3.14 Conclusions

Continuing population and consumption growth requires more food production in the developing world, where most of the farmers are resource-poor smallholders who face multifaceted challenges to meet increasing food demand for their families and livestock using good as well as marginal/saline lands. These challenges include water scarcity, poor understanding of the problem and lack of access to new technology, financial constraints, and diminished soil and water quality. Owing to these challenges many farmers have set aside marginal lands and abandoned agriculture there. Producing more food from the same area of land while reducing the environmental impact of food production requires sustainable intensification. Rather than wringing their hands in despair over these problems, the scientists of the Dubai-based International Center for Biosaline Agriculture (ICBA) are turning adversity into an advantage by providing technical support to poor farmers through the National Agricultural Research Systems (NARS) of its respective partner countries. This support includes improving soil quality and providing alternative agricultural production systems to farmers for better agricultural services leading to improved livelihoods and food security.

With these efforts ICBA has changed an adversity into an advantage in over 22 IDB member countries and has improved their livelihoods and built the capacity of professionals and farmers. It is recognized and experience shows that it is imperative that an effective extension system is to be in place that links the farming community with the latest technologies and innovations in agriculture to improve farming in order to achieve high production and facilitate participation in the market. Therefore, strong ties between research/extension and farmers are essential to benefit the final links in the chain (farmers, the stakeholders). Educating the farming community is vital in increasing awareness and understanding of salinity management for better crop production from marginal lands for food security and to reduce GHG.

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Chapter 4
Development of New Technological Approach to Mitigate Salinization

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Abstract Salinization of land has threatened civilization from ancient to modern times. To mitigate salinization, efforts have been made in the aspects of management and reclamation including using salt tolerant crops. Soybean is one of the major food and oil crops in most of the countries where salinity problems exist or are likely to be developed. Reducing the spread of salinization and increasing the salt tolerance of high yielding crops are key global issues. In this regards, an experimental design was laid out during two successive summer seasons of 2007 and 2008 at three different sites with soil salinity levels of 3.13, 6.25 and 9.38 dS m^{-1} at the experimental farm of the Faculty of Agriculture, Fayum University, Egypt. The experiment was conducted to determine how can inoculation with *Rhizobium japonicum*, *Azospirillum lipoferum* and ascorbic acid solely and in combination mitigate the negative effects of salinity on soybean growth and yield. The experiment was conducted using randomized complete block design on three different sites with soil salinity levels of 3.13, 6.25 and 9.38 dS m^{-1}, using two soybean cultivars ($Giza_{22}$ and $Giza_{111}$), 7 treatments (biofertilizer and ascorbic acid solely and their combinations) and three replications. The results revealed soil salinity significantly reduced plant height, number of leaves per plant, leaves area per plant (cm^2), shoot dry weight, total chlorophyll and total careteniods. Soil salinity significantly reduced ascorbic acid, total indoles, α-amylase activity and polyphenoloxidase activity while it increased total soluble phenols, total soluble sugars and free proline. Soil salinity decreased significantly the percentage of N, P, K, Fe, Mn, Zn and Cu while it increased Na and Cl in the plant. Soil salinity also reduced all seed yield parameters in addition to seed yield quality (protein and oil contents). No significant difference was found between both cultivars used in most measured traits. Biofertilizer treatment associated with ascorbic acid at 100 and 200 ppm showed the best results compared with other treatments (control, biofertilizer alone, ascorbic acid at 100 ppm and ascorbic acid at 200 ppm).

Keywords Antioxidant • Biofertilization • Enzymes • Salinity • Soybean

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4.1 Introduction

Salinization is the accumulation of water-soluble salts in the soil solum or regolith to a level that impacts on agricultural production, environmental health and economic welfare. Salt affected soils occur in more than 100 countries of the world with a variety of extents, nature and properties (Rengasamy 2002). In countries where salt-affected soils occur, reclamation of saline soils and increasing the salt tolerance of high yielding crops are major focus for food security. Soybean [*Glycine max* (L.) Merrill] productivity is controlled by soil and irrigation water salinity levels. In general the threshold salinity level of soybean is in the lower salinity end and therefore the soils with electrical conductivity of soil saturation extract (ECe) exceeding 3.20 dS m^{-1} would hardly support soybean growth (Coale et al. 1984). Soybean is grown as a major food and oil crop in most of the countries where salinity problems exist or are likely to be developed.

The soybean is moderately salt tolerant, and has the potential to be cultivated in slight to moderate saline soil (Grieve et al. 2003). A number of studies show that salinity reduces leaf number, leaf area, shoot dry weight and number of crowns, leading to an ultimate low yield (Hamdy et al. 1993; Essa 2002; Li et al. 2006; Sharifi et al. 2007). Moreover salinity causes physiological and biochemical changes in plants (Greenway and Muns 1980).

Inoculation with *Azospirillum* sp. under saline stress conditions is useful as it can accumulate compatible solutes, such as glycine betaine, glutamate, proline and trehalose, to allow adaptation to fluctuations in soil salinity (http://www.cjm.nrc.ca).

To minimize the effects of oxidative salt stress, antioxidant use is a must; therefore the use of ascorbic acid is generally recommended. Ascorbic acid is a small, water-soluble antioxidant molecule, which acts as a primary substrate in the cycling pathway of enzymatic detoxification of hydrogen peroxide (Foyer 1993; Smirnoff 1995).

The present work was conducted with the objective to explore how to alleviate the serious effects of soil salinity on the growth and yield of soybean, as well as to limit the physiological and biochemical changes induced through salinity stress through bio-fertilization and antioxidant application.

4.2 Materials and Methods

A field experiment was conducted during mid May of two successive summer seasons (2007 and 2008) at three different sites with soil salinity levels of 3.15, 6.25 and 9.38 dS m^{-1} at the experimental farm of the Faculty of Agriculture, Fayum University, Egypt. A randomized complete block design was used and the treatments were triplicated. The soil was sandy clay loam in texture with 1.4, 1.3, 0.86% organic matter and 3.15 dS m^{-1}, 6.25 dS m^{-1} and 9.38 dS m^{-1} soil salinities respectively (Tables 4.1–4.6). Available macro- and micronutrients are presented in

Table 4.1 Soil physical and chemical characteristics of the three sites used before planting

Property	Site 1	Site 2	Site 3
Physical			
Clay %	29	27.25	26.5
Silt %	21.5	21.75	22.00
Sand %	49.5	51	51.5
Soil texture	Sandy clay loam	Sandy clay loam	Sandy clay loam
Chemical			
pH	7.43	7.89	8.07
EC (dS m^{-1})	3.12	6.30	9.42
Organic matter %	1.41	1.30	0.86
$CaCO_3$ %	12.03	9.56	7.84
Some available macro- and micronutrients (ppm)			
N	231	206	195
P	19.57	24.69	18.0
K	258	284	280
Fe	39.41	41.16	46.92
Mn	18.50	23.00	22.26
Zn	0.34	0.36	0.31
Cu	0.21	0.20	0.24

Table 4.1. The experiment was designed and conducted to study the influence of three soil salinity levels in addition to ascorbic acid at 100 and 200 ppm together with biofertilizer application on the yield and growth parameters of two soybean cultivars ($Giza_{22}$ and $Giza_{111}$). Selected cultivars were tested and distributed by the Agricultural Research Centre as cultivars tolerant to drought and salinity.

Fertilization was accomplished using one third of the recommended dose of phosphorus at a rate of 30 kg P_2O_5/fedon (as superphosphate) during seedbed preparation, 24 kg K_2O/fedon (as potassium sulfate) was added three weeks after sowing and nitrogen fertilizer was added as a start dose two weeks after sowing at a rate of 20 kg N/fedon (as ammonium nitrate).

The biofertilization (*Azospirillum lipoferum* and *Rhizobium japonicum*) treatments were applied to the soybean seeds according to respective treatment before cultivation, where soybean seeds were inoculated with the tested biofertilizers loaded on sterilized peat moss. Firstly, soybean seeds were mixed with Arabic gum (4%) and then spread on a clean plastic sheet under a shady place for 15 min. Soybean seeds were mixed carefully with tested bacterial inocula. Ascorbic acid was sprayed twice after 3 and 5 weeks from the sowing date at the rates of 100 and 200 mg l^{-1}.

The number of nodules was counted on plant roots samples under different tested treatments after 45 days from the sowing date.

Samples from plants were collected after eight weeks to study the growth characteristics and for chemical analysis of leaves and shoots except for total chlorophyll, total carotenoids and enzymes which were analyzed in the upper fifth leaves of soybean plants. At harvest yield parameters were estimated. Soil physical and chemical analyses were carried out according to Jackson (1967).

The layout of the experiment in the present investigation was as follows:

T1: Control (positive control 100% NPK)
T2: Negative control (without any additives)
T3: *Rhizobium japonicum* + Ascorbic acid at 100 mg l^{-1} (100 ppm)
T4: *Rhizobium japonicum* + Ascorbic acid at 200 mg l^{-1} (200 ppm)
T5: *Rhizobium japonicum* + *Azospirillum lipoferum* application
T6: *Rhizobium japonicum* + *Azospirillum lipoferum* + ascorbic acid at 100 mg l^{-1}
T7: *Rhizobium japonicum* + *Azospirillum lipoferum* + ascorbic acid at 200 mg l^{-1}

The following parameters were measured: Growth parameters: plant height, number of leaves per plant, leaves area per plant (cm^2) and shoot dry weight. Yield parameters: number of pods per plant, 100 seed weight, seed yield per plant yield.

Chemical constituents: Eight weeks after planting, the fifth leaf or shoot of three selected plants was collected from each experimental unit for chemical analyses.

Chlorophylls and carotenoids were extracted from leaves by 80% acetone, then determined (mg g^{-1} FW) by using a colorimetric method (Arnon 1949). Nitrogen concentration (mg g^{-1} DW) was colorimetrically determined using the Orange G dye (Hafez and Mikkelsen 1981). To determine P, K, Fe, Mn, Zn, Cu, Na and Cl, 0.1 g fine, dry leaves from each treatments were digested with sulphuric and perchloric acid (Piper 1947). Phosphorus was determined (mg g^{-1} DW) and colorimetrically estimated using chlorostannus molybdophodphoric blue colour method in sulphuric acid system (Jackson 1967). Potassium and sodium concentration (mg g^{-1} DW) were determined with a Perkin-Elmer Flame Photometer (Page et al. 1982). Iron, manganese, zinc and copper (mg g^{-1} DW) were determined with a Perkin-Elmer Atomic Absorption Spectrophotometer (Chapman and Pratt 1961). Chlorine concentration (mg g^{-1} DW) was determined according to (Higinbotham et al. 1967).

Total soluble phenols were extracted from fresh leaves using ethanol (80%), then determined colorimetrically (mg g^{-1}) using Folin-Denis reagent by the method of Snell and Snell (1953). Total soluble sugars were determined colorimetrically (mg g^{-1} DW) by using Phosphomolybdic acid reagent according to Dubois et al. (1956). Free proline was extracted by sulfosalicylic acid (3%) then determined colorimetrically (mg g^{-1} DW) using acid minhydrin reagent as outlined by Bates et al. (1973). Total indoles (mg g^{-1} FW) were determined colorimetrically using P-dimethyl aminobenzaldehyde reagent according to (Larson et al. 1962) and as modified by (Selim et al. 1978). Ascorbic acid was determined (mg g^{-1} FW) according to AOAC (1995).

Enzyme activity—Extraction: Extraction was carried out according to Polar (1976). The 5th leaf of plants was excised and homogenized in 250 mM sucrose, 0.2 mM DTT, 2% polyvinyl polypyrolidine (W/V) and 0.1 mM EDTH, pH of grinding buffer was adjusted at 7.2 and the homogenate was filtered through four layers of cheese cloth and centrifuged at 12,000 r.p.m. for 20 min.

Peroxidase activity was determined in the supernatant according to Amako et al. (1994). The reaction mixture consisted of 1.5 ml (100 mM K phosphate buffer pH 6.8), 1.0 ml (60 mM pyrogallol), 0.48 ml (0.6 mM H_2O_2 30%) and 20 µl of the crude enzyme extract. The increase in absorbance at 430 nm was recorded using an LV-VIS-spectrophotometer, catalase activity was assayed at 240 nm (Chance and Maehly 1955) in a total volume of 1.0 ml of 25.0 mM Kphosphate buffer (pH 6.8), 10 mM H_2O_2 (30%) and a diluted enzyme extract. Polyphenoloxidase activity was determined according to the method of Taneja and Sachar (1974). The reaction mixture contained 2 ml of 1% catechol solution as substrate, 0.2 ml of enzyme extract and the rest consisted of 0.05 M sodium phosphate buffer (pH 6.8) in a final volume of 4 ml. Enzyme activity was expressed as Δ 430/5 min g^{-1} FW; α-amylase activity was determined according to the method of Petrova and Bolotina (1956) using soluble starch as a substrate and the glucose produced was estimated (as mg glucose/5 min g^{-1} FW of 5th leaf of plants) using the method for determining reducing sugars (AOAC 1995).

Data was subjected to analysis of variance according to Snedecor and Cochran (1980).

4.3 Results

The results in Table 4.2 illustrate that salt stress caused significant reductions in all growth variables including plant height, number of leaves/plant, leaf area/plant (cm^{-2}) and shoot dry weight (g/plant). As for soybean cultivars, Table 4.2 shows

Table 4.2 Effect of salinity levels, cultivars and biofertilization treatments on growth parameters of soybean plants 56 days after sowing

Treatments	Plant height (cm)	Number of leaves/plant	Leaf area/plant (cm^2)	Shoot dry weight (g/plant)
Rhizobium				
Salinity levels dS m^{-1}				
3.1	74.9	31.4	183.8	13.43
6.3	52.4	242	116.8	6.52
9.4	29.9	13.5	57.9	2.97
LSD 0.05	201	0.53	5.18	0.35
Cultivars				
$Giza_{22}$	52.8	23.2	120.9	7.73
G_{111}	52.0	22.8	118.1	7.55
LSD 0.05	N.S	N.S	1.23	0.16
Treatments				
T1 100 NPK	50.3	21.6	109.6	6.52
T2 negative control	38.4	17.7	82.3	4.55
T3 100 ppm AA	44.2	19.8	95.6	5.66
T4 200 ppm AA	53.0	22.9	119.8	7.90
T5 *Azospirillum* sp.	53.1	24.6	121.9	8.08
T6 Azo. + 100 ppm AA	61.5	25.7	143.0	9.40
T7 Azo. + 200 ppm AA	66.4	28.8	164.4	11.38
LSD 0.05	1.87	0.82	3.52	0.25

Table 4.3 Effect of salinity levels, cultivars and biofertilization treatments on total chlorophyll and total carotenoids contents of soybean plants 56 days after sowing

Treatments	Total chlorophyll (mg g^{-1} FW)	Total carotenoids (mg g^{-1} FW)
Rhizobium		
Salinity levels dS m^{-1}		
3.1	0.73	0.29
6.3	0.47	0.26
9.4	0.33	0.23
LSD 0.05	0.01	0.01
Cultivars		
$Giza_{22}$	0.52	0.26
$Giza_{111}$	0.50	0.25
LSD 0.05	N.S	N.S
Treatments		
T1 100 NPK	0.47	0.25
T2 negative control	0.39	0.24
T3 100 ppm AA	0.41	0.25
T4 200 ppm AA	0.52	0.26
T5 *Azospirillum* sp.	0.54	0.26
T6 Azo. + 100 ppm AA	0.57	0.27
T7 Azo. + 200 ppm AA	0.68	0.29
LSD 0.05	0.02	N.S

that no significant differences were found regarding plant height and leaf numbers. On the other hand, cultivar G_{22} slightly surpassed cultivar G_{111} regarding leaf area and shoot dry weight. As for the effect of various tested treatments on soybean growth parameters, Table 4.2 indicates that the combined treatments of *Azospirillum* sp. and ascorbic acid significantly exceeded the positive control.

For total chlorophylls and carotenoids (mg g^{-1} FW) affected by a high salinity level of 9.4 dS m^{-1} where the percentage decrease reached 55% and 21% for total chlorophylls and carotenoids respectively, compared to the low salinity level (3.1 dS m^{-1}).

For soybean cultivars non-significant differences were recorded for both parameters (total chlorophylls and total carotenoids). Table 4.3 also demonstrates that the highest amounts of total chlorophyll were found within the combined treatments of *Azospirillum* and ascorbic acid between various tested treatments.

As to the effect of salinity levels, cultivars and biofertilization treatments on soybean chemical constituents, Table 4.4 shows that the concentration of each of ASA (ascorbic acid), total indoles, α-amylase and PPO were reduced with increasing salinity levels. Moreover the differences in ASA content were not significant, while the variations between the other parameters were significant. On the other hand, it was found that each of TSP, TSS and proline increased with increasing salinity levels and that cultivar $Giza_{22}$ exceeded $Giza_{111}$ in ASA, TSP, total indoles and PPO concentrations (Table 4.4).

On the contrary, cultivar G_{111} exceeded variety G_{22} in each of TSS and α-amylase concentration. It is worth mentioning that the biofertilization treatment of *Azospi-*

Table 4.4 Effect of soil salinity levels, cultivars and biofertilization treatments on some chemical constituents and enzymes in soybean shoots 56 days after sowing

Treatments	ASA (mg g^{-1})	TSP (mg g^{-1})	TSS (mg g^{-1})	Proline (mg g^{-1})	Total indoles (mg g^{-1})	α-amylase (mg/ glucose)	PPO $^{\Delta}$480/5 mg g^{-1} FW
Rhizobium							
Salinity levels dS m^{-1}							
3.1	0.22	0.93	19.06	0.20	0.66	0.24	0.28
6.3	0.19	0.97	20.88	0.23	0.56	0.18	0.23
9.4	0.12	1.04	23.60	0.26	0.45	0.11	0.17
LSD 0.05	N.S	0.02	0.96	0.03	0.03	0.02	0.01
Cultivars							
$Giza_{22}$	0.18	1.00	20.74	0.23	0.57	0.17	024
$Giza_{111}$	017	0.95	21.62	0.24	0.54	0.19	0.22
LSD 0.05	0.01	0.01	0.43	N.S	0.01	0.01	0.01
Treatments							
T1 100 NPK	0.17	0.96	20.68	0.23	0.55	0.18	0.22
T2 negative control	0.13	0.92	18.27	0.16	0.51	0.13	0.19
T3 100 ppm AA	0.16	0.94	19.61	0.19	0.51	0.14	0.20
T4 200 ppm AA	0.19	0.98	20.76	0.24	0.56	0.18	0.23
T5 *Azospirillum* sp.	0.17	0.98	20.89	0.24	0.55	0.19	0.23
T6 Azo.+ 100 ppm AA	0.18	1.01	22.73	0.26	0.58	0.19	0.24
T7 Azo.+ 200 ppm AA	0.22	1.07	25.33	0.30	0.64	0.23	0.27
LSD 0.05	0.02	0.03	0.74	0.01	0.03	0.02	0.02

ASA Ascorbic acid, *TSP* Total soluble phenols, *TSS* Total soluble sugars, *PPO* Polyphenoloxidase

rillum accompanied with 200 ppm ascorbic acid recorded the highest amount of the previously mentioned chemical constituents of soybean shoots, while the bio-treatment of *Azospirillum* together with 100 ppm ascorbic acid had the second rank (Table 4.4).

Table 4.5 demonstrates the effects of different tested factors on some macro- and micronutrients in soybean shoots. For different salinity levels it was recorded that the macro- and microelements reduced with increasing salinity levels. One exception was registered where Na was the only element whose concentration increased with increasing salinity level; the differences between tested cultivars for chemical constituents are shown in Table 4.5. No significant differences were recorded for each of P, Na, Cl, Fe and Mn. On the other hand, variety $Giza_{22}$ significantly exceeded variety $Giza_{111}$ regarding K and Zn contents, while $Giza_{111}$ surpassed $Giza_{22}$ in Cu content. The effect of various tested treatments is also demonstrated in Table 4.5. Once again the biofertilization treatments of *Azospirillum* accompanied by ascorbic acid at 200 ppm recorded the highest contents of all determined elements with one exception where the Cl^{-} content was the least.

In Table 4.6 yield and yield quality (i.e. protein and oil percentages) were evaluated; it was proved that a high soil salinity level of 9.4 dS m^{-1} severely reduced

Table 4.5 Effect of soil salinity levels, cultivars and biofertilization treatments on some macro- and micronutrients in soybean shoots 56 days after sowing

Treatments	N	P	K	Na	Cl	Fe	Mn	Zn	Cu
	(mg g^{-1})					(ppm)			
Rhizobium									
Salinity levels dS m^{-1}									
3.1	10.84	3.59	10.18	2.37	1.57	242.4	144.0	83.4	70.2
6.3	6.41	2.63	8.32	3.54	2.26	223.4	133.2	75.5	63.2
9.4	5.90	2.27	7.32	4.85	3.53	198.0	125.0	68.7	55.8
LSD 0.05	0.16	0.08	0.27	0.10	0.10	4.88	3.18	1.46	0.74
Cultivars									
$Giza_{22}$	7.75	2.83	8.99	3.53	2.42	220.7	133.0	78.6	60.7
$Giza_{111}$	7.68	2.82	8.23	3.64	2.49	221.8	135.0	73.1	65.4
LSD 0.05	N.S	N.S	0.17	N.S	N.S	N.S	N.S	1.74	1.19
Treatments									
T1 100 NPK	8.33	2.91	8.28	3.87	2.63	220.9	134.2	75.9	63.2
T2 negative control	6.23	2.55	7.79	3.90	2.68	209.1	127.9	71.1	58.5
T3 100 ppm AA	6.52	2.62	7.96	3.78	2.74	214.8	130.9	73.6	60.7
T4 200 ppm AA	7.09	2.76	8.10	3.59	2.37	219.7	134.1	75.9	63.2
T5 *Azospirillum* sp.	7.99	2.81	8.29	3.49	2.37	219.9	132.9	75.3	62.8
T6 Azo. + 100 ppm AA	8.70	2.97	9.36	3.40	2.37	227.5	137.1	78.2	65.2
T7 Azo. + 200 ppm AA	9.17	3.17	10.47	3.06	2.00	237.0	141.3	81.2	67.9
LSD 0.05	0.25	0.06	0.25	0.12	0.09	4.60	2.21	1.67	1.73

Table 4.6 Effect of soil salinity levels, biofertilization treatments on yield and its attributes, protein and oil (yield quality) of soybean plants at harvest

Treatments	Pods number/plant	100 seed weight	Seed weight/ plant	Seed yield	Protein (%)	Oil (%)
Rhizobium						
Salinity levels dS m^{-1}						
3.1	16.1	12.23	7.97	096	33.14	21.55
6.3	10.2	7.36	5.23	0.63	28.05	19.51
9.4	4.2	3.11	2.17	0.26	25.17	18.19
LSD 0.05	0.77	0.50	0.48	0.06	1.61	0.43
Cultivars						
$Giza_{22}$	11.6	8.02	5.79	0.70	29.69	19.23
$Giza_{111}$	8.8	7.11	4.45	0.53	27.89	20.27
LSD 0.05	0.45	0.32	0.18	0.02	1.59	0.56
Treatments						
T1 100 NPK	10.2	7.27	5.27	0.63	28.14	19.53
T2 negative control	5.8	4.70	2.94	0.35	25.23	18.37
T3 100 ppm AA	6.6	5.42	3.32	0.40	26.44	18.97
T4 200 ppm AA	10.7	7.68	5.33	0.64	28.92	20.07
T5 *Azospirillum* sp.	10.4	7.83	5.21	0.63	27.75	19.57
T6 *Azospirillum* + 100 ppm AA	12.0	9.06	5.96	0.72	30.82	20.23
T7 *Azospirillum* + 200 ppm AA	15.7	11.01	7.80	0.94	34.19	21.51
LSD 0.05	1.18	0.46	0.55	0.07	0.89	0.66

each of the parameters, pod numbers, 100 seed weight, seed weight/plant and seed yield, but slightly reduced each of protein and oil percentages. Cultivar $Giza_{111}$ was more badly affected than $Giza_{22}$. Additional treatment with *Azospirillum* and ascorbic acid at 100 ppm T_6 and at 200 ppm T_7 was very effective in improving all yield attributes and quality of soybeans grown under saline conditions.

4.4 Discussion

In the present study, salt stress caused a significant decrease in soybean growth parameters, as salinity has both osmotic and specific ion effects on plant growth (Dionisio-Sese and Tobita 2000). The deleterious effect of salinity was attributed to salt induced stress, ion toxicities, ion imbalance or a combination of all these factors (Kurt et al. 1986). Salinity reduces leaf numbers, leaf area, shoot dry weight and numbers of crowns leading to low yields (Hamdy et al. 1993; Essa 2002; Li et al. 2006; Sharifi et al. 2007). Rengasamy (2002) interpreted the growth reduction under saline soil due to low osmotic potentials resulting from salinity that can restrain water uptake by plants, which reduce their ability to survive and produce. Yield reduction due to salinity was explained by various works (Greenway and Munns 1980; Schwarz and Gale 1981; Walker et al. 1981) which stated that salinity causes physiological and biochemical changes in plants.

Moreover, Wright et al. (1988) added that the reduction in seed number due to increasing salinity levels is believed to be the consequence of decreasing assimilate production associated with decreasing plant size.

Azospirillum is a free living, plant growth-promoting bacterium, capable of affecting growth and yield of numerous plant species, as it is capable of producing various phytohormones that improve growth (Bashan et al. 2004). *Azospirillum* sp. can accumulate compatible solutes, such as glycine betaine, glutamate, proline and trehalose, to allow adaptation to fluctuations in soil salinity/osmolarity.

Oil and protein are the two most important constituents of soybean grain, and their synthesis and deposition in the grain occurs during pod filling (Rose 1988). Decreasing oil and protein yields per plant with increasing salinity could be mainly attributed to the large reductions in grain yield per plant under saline conditions. Reduction in protein content under salinity stress also may be due to the disturbance in nitrogen metabolism or inhibition of nitrate absorption as reported by El-Zeiny et al. (2007).

Proline has a dual role in improving salt stress tolerance as it is able to act in a similar way to the peroxidase enzymes and scavenge reactive oxygen species (Zhu 2001). Protein accumulation under saline conditions may provide a storage form of nitrogen that is re-utilized when the stress is over and may play a role in osmotic adjustment (Ashraf and Harris 2004).

The activities of POD, CAT and PPO were significantly enhanced with increasing salinity. These enzymes are considered to be the main protective enzymes that play a key role in the removal of ROS. In addition, many researchers have reported that antioxidant enzymes have relatively higher activities in salt tolerant cultivars than in the sensitive ones, suggesting that higher antioxidant enzymes activities play a role in impairing the tolerance to these cultivars against environmental hazards such as salinity (Naghdi et al. 2009).

The results of the current research indicated that the added ascorbic acid improved the stem and root fresh and dry weights of salt stressed soybean plants. Consistent findings reported the beneficial effects of the exogenous application of ascorbic acid in mitigating partially the adverse effects of salt stress on growth (Mozafar and Dertli 1992).

The obtained results revealed significant effects between NaCl stress and exogenous ascorbic acid on the contents of chlorophyll, since salt stress can lead to oxidative stress through the increase in reactive oxygen species (ROS) which are highly reactive and may cause cellular damage. One of the proposed biochemical modes of ascorbate is to act as an antioxidant by scavenging hydrogen peroxide (chloroplasts lack catalase) as it forms (Miyake and Asda 1992).

Some nutritional disturbances are expected under saline conditions, resulting in high ratios of Na/Ca and Na/K. In the presence of excess NaCl in medium, Na and Cl are accumulated in plant organs, and these saline ions can affect other mineral elements uptake through competition of membranes which causes nutrient deficiencies in plants (Bohra and Döffling 1993).

The effect of salinity on the micronutrient composition of plant tissues varied depending on the cultivar. Salt stress caused ion imbalance in the soybean cultivars.

In conclusion, the combination of *Azospirillum* sp. with ascorbic acid is a new approach that appears to promote growth and yield and could be of interest for those seeking to improve salinity tolerance of crops.

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Chapter 5
Reforestation—Quality Improvement of Contaminated Mining Soil

Olaf Pollmann and Leon van Rensburg

Abstract Most sub-Saharan countries are influenced by either drought or heavy rainfall, as well as poor soil quality and anthropogenic and industrial factors. South Africa is one of the countries in the region where the greatest impact of mining on the environment is observed. These environmental impacts are obvious and need to be addressed during each phase of environmental planning, especially in rural development and improving agriculture sectors. The environmental impacts of mining in South Africa are, in general, increased concentrations of heavy metals and changes of pH in both impacted soils and in water. Mining processes coupled with weather conditions affect the agricultural and forestry sector by impacting water and soil quality. Therefore, there is need to decontaminate mining soils and to improve soil fertility for better agricultural and environmental services. In this regards the addition of different organic fertilizers to improve soil fertility, and as soil ameliorant in contaminated platinum and gold tailings, allowed the indigenous tree species—*Searsia lancea* to grow despite the high levels of contamination. In a laboratory trial with both types of tailings the combination of different fertilizers and cultivation techniques reduced up to 50% heavy metal contamination and increased ~140% microbiological activities. These experiments show a sustainable use of trees combined with fertilizers to decontaminate mine soil while producing a resource (wood) and lowering carbon dioxide, which have impacts on preventing contamination of surrounding areas by Aeolian transport (sandstorms, etc.).

Keywords Biological rehabilitation • Heavy metals • Mine soil • pH buffering • Sewage sludge • Climate change

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5.1 Introduction

South Africa is one of the sub-Saharan countries in which the highest impacts of mining activities on the environment are most evident and large areas of mining properties are highly polluted with heavy metals and sulphates and are typified by soils and water with unnaturally high or low pH and high electrical conductivity (EC) values. The ground water in these areas is highly polluted with Ca, Mg, K, Na, SO_4, NO_3, NH_4, Cl, Fe, Mn and Zn (Pollmann et al. 2010). This contamination is related to the blasting of rock with explosives, which in turn exposes new surface areas with an abundance of water-soluble elements (Hatting et al. 2003). A large amount of sludge is produced during the acid mine water (AMW) neutralization with calcium carbonate ($CaCO_3$), therefore this must be pre-treated separately due to its hazardous content and special disposal requirements (Maree et al. 2004). The sludge and the unusable soils are deposited on mine tailings storage facilities. The low soil quality, high soil bulk density due to compaction of the sediment column in a water-saturated environment and the lack of drainage facility in the soil (the ratio of horizontal permeability and vertical permeability is significantly different) (Bezuidenhout and Rousseau 2005) prohibit the establishment of planted trees, grasses or bushes under these conditions (Van Wyk and Van Wyk 1997; Carroll et al. 2000). In dry South African wintertime, permanent strong winds suspend the dust causing dust storms covering settlements, houses and the dust is inhaled by local inhabitants causing serious health hazards. The visibility may be drastically reduced by kilometre-wide dust clouds (Pollmann et al. 2008). To rehabilitate these disturbed sites, mining companies and government institutes are looking for sustainable methods for plant establishment on the slopes and on top of mine tailing dams. As a follow up to such efforts, gold and platinum tailings were tested both in the field and laboratory trials by treating them with different fertilizers and through cultivation of the indigenous plant species *Searsia lancea*. The aim of these experiments was to establish growth of the experimental plants and to improve the quality of the polluted soil.

5.2 Materials and Methods

5.2.1 Laboratory and Field Trial

For both, laboratory and field trials, gold and platinum tailings as well as natural soil (as a control sample) were collected from mining concessions in the northern part of South Africa—Rustenburg and Orkney (North-West Province). For the laboratory trials (12 test plants per type): ameliorants such as sewage sludge, woodchips and vermicompost were used (Maboeta and Rensburg 2003a, b). Twelve test plants were also cultivated in the control soil. A total of 144 plants were initially kept in a greenhouse with regular irrigation twice per week over the first three months prior to their transfer to natural, uncovered conditions with only natural irrigation, in the form of rainfall, for another three months. A field trial was conducted on platinum tailings in Rustenburg (North-West Province, 25° 31′ 07.92″ S; 27° 13′ 12.54″ E). Four different ameliorant types were used (20 test plants per type): 5% sewage sludge matured, 15% sewage sludge matured, 10% woodchips, 10% compost. The selected ratios of the ameliorants are results of former research to optimize the use of fertilizers and ameliorants on different polluted soil types (Maboeta and Rensburg 2003a, b). These soil ameliorants are functioning as plant fertilizers as well. Unaltered platinum tailings material was used as control soil. All plants were irrigated every second week, three times; only then the plants adapted to the natural regional rainfall. Rustenburg falls within the Summer Rainfall Climatic Zone. The area is characteristically warm to hot with a mean annual precipitation of about 600 mm and a mean annual evaporation of about 1,800 mm (Midgley et al. 1994a). Temperatures vary between extremes of −6.0°C and 40°C with an average of 19°C (Rustenburg Local Municipality 2009). The soil geology is basic, mafic and ultramafic intrusive (Midgley et al. 1994b).

5.2.2 *Quality of Polluted Mining Soil*

Mine tailings material is typified by altered pH and high EC (measured with handheld Combo pH and EC, HI 98130 by HANNA). The gold tailings material had EC 3.05 mS cm^{-1} and a pH of 3.75 at the beginning of the trial. Concentrations of Ca (464 ppm), Mg (71 ppm), SO_4 (1,430 ppm), Mn (13 ppm), Cu (0.5 ppm) and Zn (3 ppm) were also high (Tables 5.1 and 5.2) in gold tailings. Platinum tailings are similar in composition to the gold tailings but had a pH of 7.34 and an EC of 1.24 mS cm^{-1} at the beginning of the trial (Tables 5.1 and 5.2). Specifically the concentrations of the elements Ca (82 ppm), Mg (54 ppm), Na (75 ppm), SO_4 (351 ppm), Cl (115 ppm) and Mn (0.02 ppm) were also of concern (Tables 5.1 and 5.2). Each plant has favourable soil and nutrient parameters but in this type of substrate, plants struggle to survive because of low concentrations of essential nutrients and high concentrations of phytotoxic substances. In the laboratory trial, some of the water-soluble salts were washed out by irrigation. This differs from the field trial where the high content of pollutants and dense soil inhibited such losses through leaching. Additionally, the high evaporation rate in these areas shows precipitation of salt on the surface of both tailing types. The soil samples for each different substrate type (pot/tailings) were taken in different soil layers (top, 10 cm, 20 cm) and mixed afterwards to get one representative sample for the different types of analyses.

5.2.3 *Ameliorants*

The organic materials used in the present study were produced from natural materials and optimized for the specific needs of the plants. Three different materials were used

Table 5.1 Analysis of the compost, control soil and polluted mine tailings material (macroelements)

Sample	Time frame	Macro-elements									
		Ca	Mg	K	Na	PO_4	SO_4	NO_3	NH_4	Cl	HCO_3
		ppm									
General limitations	–	72,14	14,58	31,28	22,99	0,95	86,46	130,21	7,22	35,45	48,81
Control Soil	start	144,68	43,02	47,31	13,10	0,00	88,38	642,98	8,46	27,30	6,10
Control Soil	after 2 month	24,45	12,64	8,21	28,74	0,53	106,63	14,88	0,04	34,66	21,36
Control Soil	after 6 month	2,81	1,22	2,74	1,84	2,37	12,49	1,25	0,43	0,98	6,10
Gold Soil	start	464,10	70,73	0,39	17,70	0,00	1.429,40	18,02	2,20	16,57	0,00
Gold Soil	after 2 month	424,43	38,16	4,30	27,36	0,00	1.176,76	11,65	0,76	27,30	6,10
Gold Soil	after 6 month	435,65	9,72	4,69	7,82	1,64	1.094,15	5,95	1,10	2,53	0,00
Platinum Soil	start	81,76	54,44	22,68	74,95	0,00	350,63	78,36	0,60	115,15	36,61
Platinum Soil	after 2 month	32,86	37,92	15,64	52,88	0,00	185,40	8,55	0,67	98,20	42,71
Platinum Soil	after 6 month	8,82	2,19	5,08	1,61	0,07	2,88	1,24	0,25	0,59	48,81
Compost	start	9,62	6,56	5,08	26,67	6,04	49,23	4,00	0,43	35,02	6,71
Compost	after 2 month	37,27	33,30	4,69	51,27	0,00	205,57	0,49	0,27	86,86	15,25
Compost	after 6 month	10,02	10,21	1,56	15,86	1,79	61,48	4,34	1,01	20,56	12,20

Table 5.2 Analysis of the used compost, control soil and polluted mine tailings material (microelements)

Sample	Time frame	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)	B (ppm)	pH	EC (mS/cm)	P-BRAY 1 (ppm)
General limitations	–	0,56	0,05	0,05	0,06	0,11	6.5 - 6.7	0.8 - 2.1	–
Control Soil	start	0,24	0,49	0,02	0,01	0,00	4,90	1,31	41,61
Control Soil	after 2 month	2,10	0,04	0,04	0,01	0,09	6,23	0,38	34,52
Control Soil	after 6 month	1,74	0,39	0,11	0,15	0,19	5,68	0,05	36,38
Gold Soil	start	0,36	12,93	0,54	2,89	0,00	3,75	3,05	3,79
Gold Soil	after 2 month	0,05	1,55	0,05	0,06	0,00	5,25	2,56	3,47
Gold Soil	after 6 month	0,00	1,87	0,05	0,17	0,04	4,32	2,31	4,13
Platinum Soil	start	0,06	0,02	0,00	0,00	0,05	7,34	1,24	3,96
Platinum Soil	after 2 month	0,00	0,02	0,01	0,00	0,00	7,34	0,75	3,99
Platinum Soil	after 6 month	1,80	0,10	0,07	0,01	0,10	7,38	0,09	5,48
Compost	start	1,81	0,10	0,02	0,01	0,14	5,52	0,24	40,21
Compost	after 2 month	0,63	0,14	0,04	0,04	0,06	6,06	0,70	20,62
Compost	after 6 month	1,93	0,14	0,02	0,03	0,11	5,46	0,22	–

for cultivation of the experimental plants. The sewage sludge used was aged for an average of six months. The woodchips were obtained from the destruction of underground supporting struts after blasting. These woodchips contain, in addition to high concentrations of plastic as residues from explosives, high concentrations of nutrients necessary for the growth of the plants. The third organic fertilizer used is compost, a typical growth medium and nutrient repository. All three different organic fertilizers materials were used to maximize the affinity to obtain the best binding, related to the lyotrophic series (conversion preference, $Al^{3+} \approx H^{+} \gg Ca^{2+} > Mg^{2+} \gg K^{+} \approx NH_4^{+} > Na^{+}$; Scheffer and Schachtschabel 2002) and to store the required nutrients. All organic fertilizers materials have different influences on soil quality and tree vitality because of the content and variety of available and essential nutrients. Transformation and metabolism of elements from the substrate by plants change the quality of the soil in question. After the application of different fertilizers, soil/substrate quality was analysed for macro-, microelements by straight water analysis (1 : 2 water extraction) and Inductively Coupled Plasma Mass-Spectrometry (ICP-MS, Agilent 7500c, Agilent Technologies, Santa Clara, California, USA). Microbiological activity was analysed by testing enzyme activity and dehydrogenase activity (Von Mersi and Schinner 1991).

5.2.4 Selected Tree Species—*Searsia lancea* (Linnaeus F.) F. A. Barkley Syn. *Rhus Lancea* Linnaeus F.

To explore improvement in the quality of soil/tailings material it is essential to establish the vegetation on the substrate to assess the capacity of phytoremediation. An indigenous (South African) tolerant and easily adaptable tree species *S. lancea* was selected to establish different stages of reforestation on the polluted mine tailings. *S. lancea* is a small to medium sized evergreen tree that usually grows to a height of 7 m and a width of 7 m but can be larger depending on environmental factors. The leaves are compound, trifoliate (a compound leaf with three leaflets) possessing narrowly lanceolate (lance shaped) leaflets. The *S. lancea* can adapt well to different soils including those that are poorly drained (Van Wyk and Van Wyk 1997). At replanting time, the trees were 1.2–1.5 m high and the average age was about two years. The threshold EC value for *S. lancea* is between 0.8 and 1.2 mS cm^{-1}.

5.2.5 Control Methods of Microbiological Activity—Dehydrogenase Activity

Microbiological activity was determined by testing dehydrogenase activity using the INT-method (INT = iodonitrotetrazolium chloride) after Von Mersi and Schinner (1991). The method is based on the incubation of soil with the substrate iodonitrotetrazolium chloride (INT) at 40°C for 2 h followed by colorimetric estimation of the reaction product iodonitrotetrazolium chloride-formazan (INF) spectrophotometrically at 464 nm against the blank. The amount of metabolised substrate per time and amount of protein was measured. Dehydrogenase activity is expressed as µg INF g^{-1} dwt 2 h^{-1} and calculated according to the following equation:

$$INF(\mu g g^{-1} dwt 2h^{-1}) = \frac{S_1 - S_0}{dwt} \tag{5.1}$$

with:

S_1 = INF (in μg) of the test
S_0 = INF (in μg) of the control
dwt = dry weight of 1 g moist soil

5.3 Results and Discussion

5.3.1 Visual Differences in Plant Growth

After two weeks of growth in the mine tailings, a difference between the plants could easily be visually detected. Trees growing in unaltered gold tailings material (gold soil) showed signs of dieback possibly due to the toxic content in the slimes material with a number of plant deaths in all different groups of ameliorants. Yellow-brown discolouration on the leaves indicated stress related to nutrient overdose and non-ideal growth conditions. The same symptoms, but more pronounced, were detected on the leaves of trees growing in platinum tailings (platinum soil). The trees growing in the control soil had no visual signs of any negative influence on their growth and only one of the trees died. In contrast to the laboratory trial, the trees in the field trial on the tailings storage facilities had to endure near-natural conditions. However, the plants were irrigated every second week for the total trial in addition to rainfall. After the initial phase of stress from replanting, the trees recovered well and their appearance was similar with no mortalities in the first two months. After an additional two months the mortality in the control group was one tree out of 20, in the group with 10% additional compost two out of 20 trees and in the group with the woodchip ameliorant one out of 20 trees with one tree recovering. In total, the mortality of the trees was very low.

5.3.2 Differences in Soil Quality

The use of pre-treated fertilizer in polluted tailings showed an improvement in soil quality after only two months of plant growth (Tables 5.1 and 5.2). The elements Na, Mg, PO_4, Cl, NO_3 and NH_4 in the treated gold and platinum soil in particular were significantly reduced in the laboratory trial. In addition, in the platinum soil the elements Ca and SO_4 were also significantly reduced (Tables 5.3 and 5.4).

Table 5.3 Lab test: quality change in soil and tailings chemistry (macroelements)

Sample	Time frame	Macro-elements									
		Ca	Mg	K	Na	PO_4	SO_4	NO_3	NH_4	Cl	HCO_3
		ppm									
Control Soil + woodchips (CWC)	start	115.42	33.05	63.73	14.02	0.00	105.67	502.23	8.17	28.72	6.10
Control Soil + woodchips (CWC)	after 2 month	43.28	15.80	21.11	38.62	0.00	203.65	0.70	0.13	45.38	9.15
Control Soil + woodchips (CWC)	after 6 month	7.21	3.16	11.34	5.98	1.11	34.58	2.48	0.79	6.74	18.30
Control Soil + compost (CVC)	start	115.42	30.87	44.18	14.94	10.45	95.10	476.19	11.92	23.75	6.10
Control Soil + compost (CVC)	after 2 month	35.67	13.85	8.21	28.05	0.71	122.00	7.44	0.14	40.42	33.56
Control Soil + compost (CVC)	after 6 month	6.41	1.70	5.47	3.91	2.54	9.70	1.23	1.06	3.34	30.51
Control Soil + sewage sludge (CSH)	start	69.74	40.83	56.69	17.01	14.41	116.24	456.35	39.47	27.30	15.25
Control Soil + sewage sludge (CSH)	after 2 month	90.98	60.03	32.84	62.53	41.49	222.86	280.88	0.40	86.86	6.10
Control Soil + sewage sludge (CSH)	after 6 month	6.01	1.70	5.08	2.53	9.65	10.57	4.96	0.61	2.32	6.10
Control Soil (CCO)	start	144.68	43.02	47.31	13.10	0.00	88.38	642.98	8.46	27.30	6.10
Control Soil (CCO)	after 2 month	24.45	12.64	8.21	28.74	0.53	106.63	14.88	0.04	34.66	21.36
Control Soil (CCO)	after 6 month	2.81	1.22	2.74	1.84	2.37	12.49	1.25	0.43	0.98	6.10
Gold Soil + woodchips (GWC)	start	446.07	84.10	3.52	29.66	0.00	1,453.42	24.12	2.58	27.04	0.00
Gold Soil + woodchips (GWC)	after 2 month	352.29	47.39	10.95	18.16	0.00	1,034.59	7.56	0.72	23.06	12.20
Gold Soil + woodchips (GWC)	after 6 month	422.02	11.18	8.99	6.90	0.00	1,081.66	7.01	0.52	2.68	0.00
Gold Soil + compost (GVC)	start	434.85	99.41	7.43	31.04	0.00	1,443.81	149.12	18.36	19.23	0.00
Gold Soil + compost (GVC)	after 2 month	411.60	50.07	5.47	22.99	0.00	1,204.62	8.61	1.68	24.43	6.10
Gold Soil + compost (GVC)	after 6 month	422.82	12.15	4.30	5.29	0.41	1,072.05	9.11	0.97	1.56	0.00
Gold Soil + sewage sludge (GSH)	start	401.58	70.73	8.21	17.24	1.90	1,505.29	11.34	87.02	17.13	0.61
Gold Soil + sewage sludge (GSH)	after 2 month	321.43	69.03	3.52	20.00	0.00	1,036.51	30.21	1.23	16.31	15.25
Gold Soil + sewage sludge (GSH)	after 6 month	367.11	13.61	2.35	4.14	0.17	938.53	6.84	0.81	1.70	0.00
Gold Soil (GCO)	start	464.10	70.73	0.39	17.70	0.00	1,429.40	18.02	2.20	16.57	0.00
Gold Soil (GCO)	after 2 month	424.43	38.16	4.30	27.36	0.00	1,176.76	11.65	0.76	27.30	6.10
Gold Soil (GCO)	after 6 month	435.65	9.72	4.69	7.82	1.64	1,094.15	5.95	1.10	2.53	0.00
Platinum Soil + woodchips (PWC)	start	340.66	149.23	104.39	245.99	0.00	1,081.66	268.48	0.40	548.81	33.56
Platinum Soil + woodchips (PWC)	after 2 month	58.51	59.06	25.02	65.98	0.00	347.74	1.17	0.47	92.89	88.47
Platinum Soil + woodchips (PWC)	after 6 month	10.42	3.65	7.82	4.37	0.08	10.57	0.41	0.22	2.34	61.02
Platinum Soil + compost (PVC)	start	228.44	93.82	67.25	129.43	0.00	800.20	190.35	3.25	219.81	39.66
Platinum Soil + compost (PVC)	after 2 month	23.65	21.63	8.60	20.23	0.00	97.02	4.03	0.22	20.56	88.47
Platinum Soil + compost (PVC)	after 6 month	10.02	5.10	5.86	3.45	0.55	10.57	2.96	0.41	2.02	57.97
Platinum Soil + sewage sludge (PSH)	start	72.14	86.28	38.32	93.34	39.22	402.50	97.97	14.52	152.80	64.07
Platinum Soil + sewage sludge (PSH)	after 2 month	34.47	33.05	13.68	34.71	1.76	139.29	22.94	0.32	52.47	91.52
Platinum Soil + sewage sludge (PSH)	after 6 month	5.61	3.40	3.91	1.61	2.81	5.47	6.20	0.16	1.67	27.46
Platinum Soil (PCO)	start	81.76	54.44	22.68	74.95	0.00	350.63	78.36	0.60	115.15	36.61
Platinum Soil (PCO)	after 2 month	32.86	37.92	15.64	52.88	0.00	185.40	8.55	0.67	98.20	42.71
Platinum Soil (PCO)	after 6 month	8.82	2.19	5.08	1.61	0.07	2.88	1.24	0.25	0.59	48.81
Compost	start	9.62	6.56	5.08	26.67	6.04	49.23	4.00	0.43	35.02	6.71
Compost	after 2 month	37.27	33.30	4.69	51.27	0.00	205.57	0.49	0.27	86.86	15.25
Compost	after 6 month	10.02	10.21	1.56	15.86	1.79	61.48	4.34	1.01	20.56	12.20

Table 5.4 Lab test: quality change in soil and tailings chemistry (microelements)

Sample	Time frame	Micro-elements and other data							P-BRAY 1
		Fe	Mn	Cu	Zn	B	pH	EC	
		ppm						*(mS/cm)*	*ppm*
Control Soil + woodchips (CWC)	start	0.11	1.81	0.02	0.02	0.00	4.74	1.12	40.81
Control Soil + woodchips (CWC)	after 2 month	0.64	0.06	0.02	0.00	0.03	5.69	0.57	32.99
Control Soil + woodchips (CWC)	after 6 month	1.89	0.31	0.10	0.13	0.15	5.93	0.13	40.13
Control Soil + compost (CVC)	start	0.08	0.99	0.01	0.02	0.00	5.01	1.08	51.85
Control Soil + compost (CVC)	after 2 month	0.64	0.06	0.02	0.00	0.03	5.69	0.57	32.99
Control Soil + compost (CVC)	after 6 month	1.72	0.32	0.11	0.15	0.10	6.63	0.09	53.63
Control Soil + sewage sludge (CSH)	start	0.47	1.01	0.02	0.01	0.06	5.71	1.13	11.12
Control Soil + sewage sludge (CSH)	after 2 month	0.19	0.09	0.05	0.02	0.07	5.20	1.31	146.03
Control Soil + sewage sludge (CSH)	after 6 month	1.91	0.29	0.14	0.19	0.30	5.23	0.08	136.88
Control Soil (CCO)	start	0.24	0.49	0.02	0.01	0.00	4.90	1.31	41.61
Control Soil (CCO)	after 2 month	2.10	0.04	0.04	0.01	0.09	6.23	0.38	34.52
Control Soil (CCO)	after 6 month	1.74	0.39	0.11	0.15	0.19	5.68	0.05	36.38
Gold Soil + woodchips (GWC)	start	0.32	12.99	0.47	2.87	0.00	3.86	3.14	3.94
Gold Soil + woodchips (GWC)	after 2 month	0.01	1.20	0.03	0.03	0.00	6.70	2.26	3.47
Gold Soil + woodchips (GWC)	after 6 month	0.45	0.67	0.02	0.09	0.00	4.29	2.26	3.98
Gold Soil + compost (GVC)	start	0.17	12.33	0.11	2.88	0.00	3.88	3.30	12.38
Gold Soil + compost (GVC)	after 2 month	0.06	2.79	0.03	0.09	0.00	5.07	2.59	5.29
Gold Soil + compost (GVC)	after 6 month	0.08	0.95	0.01	0.09	0.00	4.37	2.26	7.38
Gold Soil + sewage sludge (GSH)	start	0.10	12.43	0.05	1.59	0.00	4.54	3.20	103.88
Gold Soil + sewage sludge (GSH)	after 2 month	0.04	0.68	0.04	0.03	0.01	6.47	2.27	49.85
Gold Soil + sewage sludge (GSH)	after 6 month	0.10	0.42	0.01	0.10	0.03	4.42	1.98	57.38
Gold Soil (GCO)	start	0.36	12.93	0.54	2.89	0.00	3.75	3.05	3.79
Gold Soil (GCO)	after 2 month	0.05	1.55	0.05	0.06	0.00	5.25	2.56	3.47
Gold Soil (GCO)	after 6 month	0.00	1.87	0.05	0.17	0.04	4.32	2.31	4.13
Platinum Soil + woodchips (PWC)	start	0.21	0.11	0.03	0.02	0.00	6.86	4.28	3.59
Platinum Soil + woodchips (PWC)	after 2 month	0.02	0.03	0.04	0.02	0.00	7.66	1.13	3.88
Platinum Soil + woodchips (PWC)	after 6 month	1.90	0.10	0.14	0.02	0.06	7.70	0.13	74.63
Platinum Soil + compost (PVC)	start	0.15	0.38	0.05	0.03	0.00	7.07	2.67	9.41
Platinum Soil + compost (PVC)	after 2 month	0.37	0.01	0.07	0.00	0.00	7.45	0.41	8.00
Platinum Soil + compost (PVC)	after 6 month	1.55	0.06	0.09	0.02	0.02	7.48	0.13	7.93
Platinum Soil + sewage sludge (PSH)	start	0.06	0.07	0.00	0.00	0.16	7.53	1.65	65.70
Platinum Soil + sewage sludge (PSH)	after 2 month	0.00	0.00	0.00	0.00	0.00	7.74	0.63	50.73
Platinum Soil + sewage sludge (PSH)	after 6 month	1.74	0.04	0.03	0.02	0.03	7.12	0.08	58.13
Platinum Soil (PCO)	start	0.06	0.02	0.00	0.00	0.05	7.34	1.24	3.96
Platinum Soil (PCO)	after 2 month	0.00	0.02	0.01	0.00	0.00	7.34	0.75	3.99
Platinum Soil (PCO)	after 6 month	1.80	0.10	0.07	0.01	0.10	7.38	0.09	5.48
Compost	start	1.81	0.10	0.02	0.01	0.14	5.52	0.24	40.21
Compost	after 2 month	0.63	0.14	0.04	0.04	0.06	6.06	0.70	20.62
Compost	after 6 month	1.93	0.14	0.02	0.03	0.11	5.46	0.22	–

A total reduction of ionic compounds could be shown by a decrease in the electrical conductivity (EC) of 97% in the platinum tailings treated with woodchips and 38% in gold tailings treated with matured sewage sludge. In this application, the pre-treated fertilizer has the ability to exchange and bind the elements by the lyotrophic series (Scheffer and Schachtschabel 2002). Because of nitrogen fixing micro-organisms (diastrophic organisms) in the organic fertilizer, the amount of nitrogen from nitrate (NO_3) and ammonium (NH_4) was lower after treatment. Microorganisms, for example *Rhizobium* or *Frankia,* live in symbiosis with the roots of the plants, use ammonia for protein biosynthesis for amino-acids and change the ammonia against carbon to produce energy as adenosine-triphosphate (ATP). The total available phosphorous, essential for the plants, detected with the method P-Bray 1, increased in the control soil + sewage sludge (CSH) due to the residues mineralization from the matured sewage sludge (Table 5.4). In total, all ameliorants used lead to an increased quality in both types of polluted tailings after the treatment period

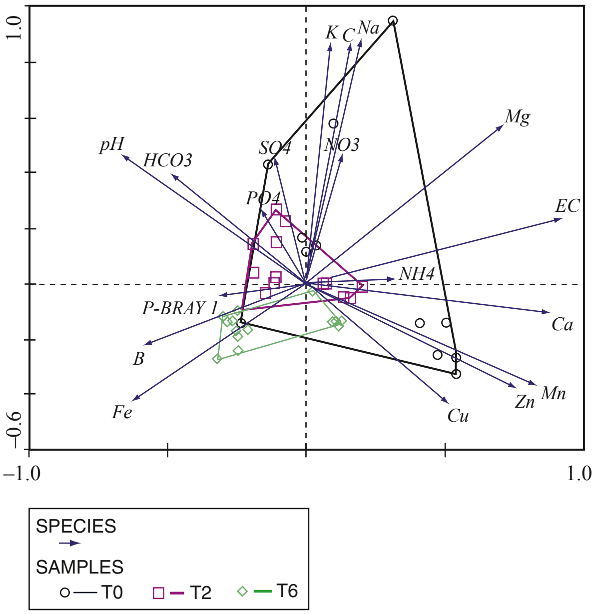

Fig. 5.1 Lab test: multivariate analysis of performing principle components by *Canoco*

of six months (Fig. 5.1). Additionally the *Searsia lancea* trees aided the process by utilizing essential elements and nutrients for their growth and nutrient balance.

A relative comparison between the different ameliorants clearly shows the benefit of matured sewage sludge and woodchips in improving the quality of the tailings in terms of most of the chemical indicators in the laboratory trial. The platinum tailings treated with woodchips showed a decrease in all elements except for manganese (Mn) which was not reduced as expected. In the gold tailings, the woodchips could reduce the concentrations of all macro- and microelements with the exception of calcium (Ca) and sulphate (SO_4). These two elements could not be reduced under the limits of acceptable agricultural soil quality by any of the ameliorants used in the laboratory trails (Table 5.4). The results from using matured sewage sludge are similar. This ameliorant work was successful in both tailings types but did not reduce the concentrations of calcium (Ca) and sulphate (SO_4) to the expected levels. The laboratory trials with different ameliorants showed a clear reduction in the concentrations of pollutants and improvement in total soil quality in all different soil types with only a slight improvement with the woodchips. Similar but better results were demonstrated in the field trials in platinum tailings ameliorated with woodchips, compost and matured sewage sludge (Tables 5.5 and 5.6, Fig. 5.2). All plants showed strong growth and the ameliorants improved soil quality. This trial was focused on the ameliorants with similar compositions but at different concentrations. This fact explains the similarity in the results in soil quality improvement. All ameliorant treatments did not reduce the concentrations of phosphate (PO_4), sulphate (SO_4), iron (Fe), manganese (Mn) and copper (Cu). After amelioration, the pH of the soil was stable and the total EC was reduced by 47% on average (Tables 5.3 and 5.4, Fig. 5.2).

Table 5.5 Field test: quality change in soil and tailings chemistry (macroelements)

Sample	Time frame	Ca	Mg	K	Na	PO_4	SO_4	NO_3	NH_4	Cl	HCO_3
		Macro-elements (*ppm*)									
Woodchips 10% (dry, IWCL)	start	28.46	14.83	22.29	46.67	29.44	77.81	86.98	0.51	13.30	57.97
Woodchips 10% (dry, IWCL)	after 2 month	10.42	5.35	8.99	18.62	18.80	24.98	6.57	0.67	4.93	45.76
Woodchips 10% (dry, IWCL)	after 4 month	18.04	3.40	7.43	2.76	7.44	17.29	10.87	0.70	2.80	45.76
Compost 10% (Woodchips + Sewage Sludge, IWCH)	start	14.43	6.81	2.74	36.09	14.25	30.74	13.38	0.32	9.68	85.42
Compost 10% (Woodchips + Sewage Sludge, IWCH)	after 2 month	9.62	3.65	8.21	14.48	9.78	17.29	2.48	0.36	4.96	51.86
Compost 10% (Woodchips + Sewage Sludge, IWCH)	after 4 month	16.83	4.13	12.12	22.99	10.49	39.39	13.02	0.36	8.51	61.02
Sewage Sludge 5% (matured, ISSL)	start	14.83	11.42	21.11	54.72	42.74	52.83	58.90	0.67	6.74	67.12
Sewage Sludge 5% (matured, ISSL)	after 2 month	14.83	8.75	12.51	23.45	17.84	33.39	50.22	0.49	4.15	42.71
Sewage Sludge 5% (matured, ISSL)	after 4 month	14.43	4.13	6.65	3.91	10.87	17.64	13.25	0.51	2.20	30.51
Sewage Sludge 15% (matured, ISSH)	start	22.04	10.94	15.64	32.42	21.84	47.07	71.30	3.88	9.24	61.02
Sewage Sludge 15% (matured, ISSH)	after 2 month	28.05	15.80	24.63	36.09	27.54	72.05	117.81	2.25	5.67	39.66
Sewage Sludge 15% (matured, ISSH)	after 4 month	25.65	6.81	12.51	7.13	11.07	30.91	52.70	0.79	3.90	39.66
Control soil (platinum, ICON)	start	16.03	5.10	0.39	17.93	6.30	14.41	9.92	0.38	4.41	79.32
Control soil (platinum, ICON)	after 2 month	12.02	5.83	5.86	13.10	10.00	19.21	4.23	0.67	3.33	61.02
Control soil (platinum, ICON)	after 4 month	26.85	6.56	17.59	8.28	13.07	45.27	34.70	0.92	4.64	45.76
Compost pure	start	197.99	446.73	486.77	237.95	717.97	1,160.43	1,146.45	35.77	173.37	73.22
Sewage sludge pure	start	46.89	25.76	186.50	84.14	1,122.55	3,169.09	270.00	2,048.10	154.49	1,049.47

Table 5.6 Field test: quality change in soil and tailings chemistry (microelements)

Sample	Time frame	Fe	Mn	Cu	Zn	B	pH	EC	P-BRAY 1
		Micro-elements and other data							
		ppm						(mS/cm)	ppm
Woodchips 10% (dry, IWCL)	start	19.63	0.57	1.15	0.36	8.13	7.09	0.53	160.00
Woodchips 10% (dry, IWCL)	after 2 month	1.67	0.09	0.18	0.03	0.00	7.12	0.21	217.85
Woodchips 10% (dry, IWCL)	after 4 month	1.70	0.18	0.16	0.06	0.00	6.88	0.16	91.35
Compost 10% (Woodchips + Sewage Sludge, IWCH)	start	21.10	1.90	1.11	0.69	12.32	7.46	0.30	158.33
Compost 10% (Woodchips + Sewage Sludge, IWCH)	after 2 month	1.53	0.14	0.19	0.05	0.00	7.15	0.17	155.35
Compost 10% (Woodchips + Sewage Sludge, IWCH)	after 4 month	2.00	0.14	0.20	0.07	0.00	6.84	0.26	115.28
Sewage Sludge 5% (matured, ISSL)	start	21.37	1.13	1.88	0.55	0.23	7.18	0.47	308.33
Sewage Sludge 5% (matured, ISSL)	after 2 month	1.66	0.09	0.19	0.05	0.01	7.00	0.29	355.35
Sewage Sludge 5% (matured, ISSL)	after 4 month	1.75	0.10	0.15	0.04	0.19	6.82	0.15	168.45
Sewage Sludge 15% (matured, ISSH)	start	19.04	0.91	1.88	0.39	0.81	7.19	0.41	260.00
Sewage Sludge 15% (matured, ISSH)	after 2 month	1.72	0.06	0.46	0.02	0.22	6.92	0.51	162.98
Sewage Sludge 15% (matured, ISSH)	after 4 month	2.00	0.10	0.17	0.03	0.20	6.74	0.26	98.10
Control soil (platinum, ICON)	start	18.70	1.49	3.69	0.23	9.18	7.48	0.21	39.17
Control soil (platinum, ICON)	after 2 month	1.43	0.12	0.17	0.01	0.20	7.33	0.19	127.57
Control soil (platinum, ICON)	after 4 month	1.53	0.10	0.29	0.04	0.20	6.89	0.28	112.20
Compost pure	start	12.51	32.38	17.64	2.14	185.95	5.42	7.16	1,970.84
Sewage sludge pure	start	20.24	2.42	232.57	1.56	67.23	7.05	12.77	3,087.50

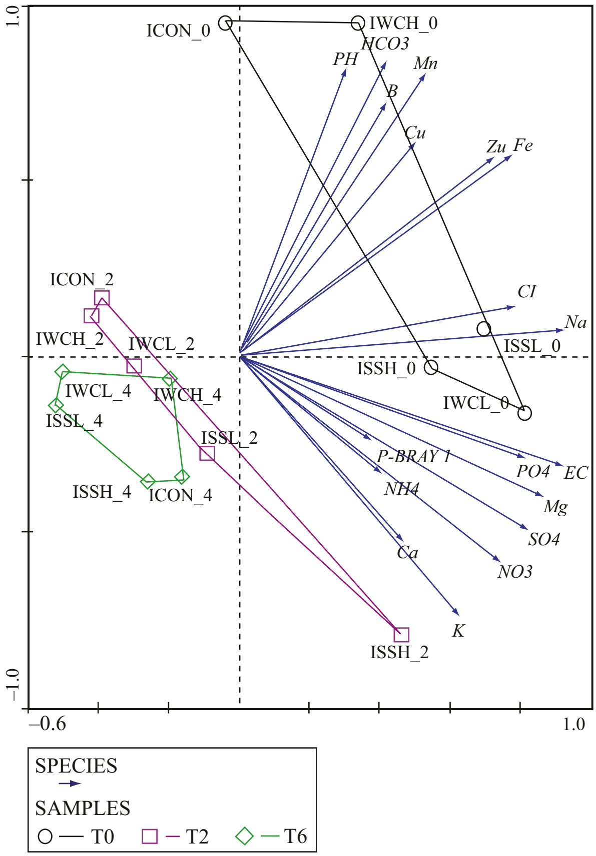

Fig. 5.2 Field test: multivariate analysis of performing principle components by *Canoco*

The field trials with platinum tailings supported the results of the laboratory trials. The use of organic fertilizers changes the soil quality and supports the plant growth. However, the field trial showed small benefit in the use of compost and in the 15% addition of matured sewage sludge.

5.3.3 Differences in Microbiological Activity

The total microbiological activity in both unaltered tailings and ameliorated soil types was only about one third, on average about 50 [INF µg/(g*2h)], compared to the conditions in natural soil—110 [INF µg/(g*2h)]. This is the result of the freely available inhibitors of microbial growth in the polluted tailings. These substances block the metabolism of the microorganisms and inhibit total activity. The benefit of adding ameliorants can be seen in initially higher microbiological activity and a deposit function of the most needed and available nutrients for the microorganisms after two months. The microbiological activity in gold tailings ameliorated

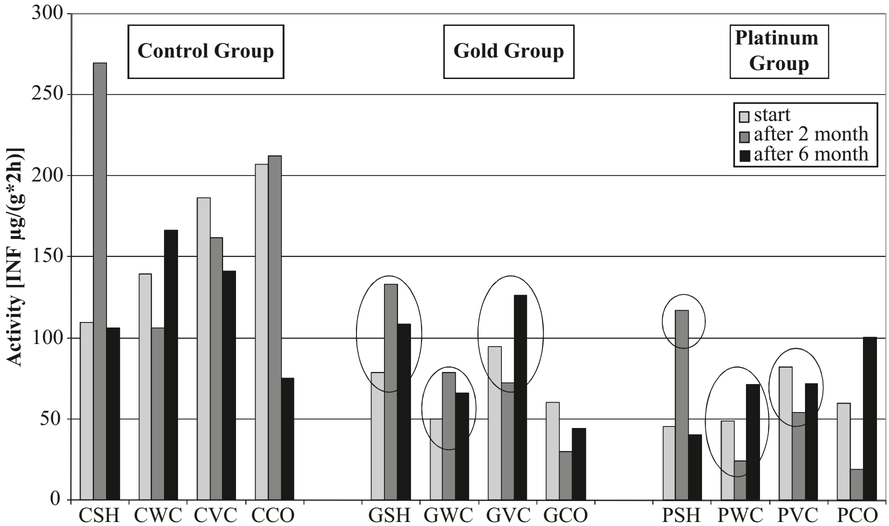

Fig. 5.3 Lab test: quality change of microbiological activity in the different soil types

with sewage sludge and vermicompost after two months, improved; 78.3 [INF µg/(g*2h)] with sewage sludge, 94.7 [INF µg/(g*2h)] with vermicompost and better than the initial microbiological activity of untreated tailings of 60.3 [INF µg/(g*2h)] (Fig. 5.3). In gold tailings the initial microbiological activity in tailings ameliorated with vermicompost was 81.9 [INF µg/(g*2h)] and is higher than the untreated gold tailings with 59.9 [INF µg/(g*2h)]. The microbiological activity of the other ameliorated soil types was lower. After two months the microbiological activity of all other ameliorated soil types (GCO, PCO) was lower than the unameliorated soil (CCO) with 207.3 [INF µg/(g*2h)] before it dropped to 75.3 [INF µg/(g*2h)] after six months (Fig. 5.3). The improvement of soil quality can clearly be seen in gold tailings with the ameliorant—matured sewage sludge. After the addition of the ameliorant the microbiological activity increased by about 69.6% from 78.3 to 132.8 [INF µg/(g*2h)] after two months and stabilised at 108.2 [INF µg/(g*2h)] after six months (Fig. 5.3). In the platinum tailings the most improvement in microbiological activity was achieved after an initial decrease of 51% after two months using woodchips followed by a 46% increase from 48.7 to 71.1 [INF µg/(g*2h)] after the total six months test period (Fig. 5.3).

An increase in microbiological activity after the first two months and a drastic drop after six months indicates that the storage capacity of the fertilizer is not effective enough to support the plants over a long period of time. The microbiological activity in the unpolluted natural soil was only improved with woodchips as an ameliorant by 19.3% from 139.2 to 166.1 [INF µg/(g*2h)] after six months. All other ameliorated tailings as well as the untreated soil showed a decrease in microbiological activity over time (Fig. 5.3). Unlike the laboratory trial, the microbiological activity in the field trial with platinum tailings was improved when using all

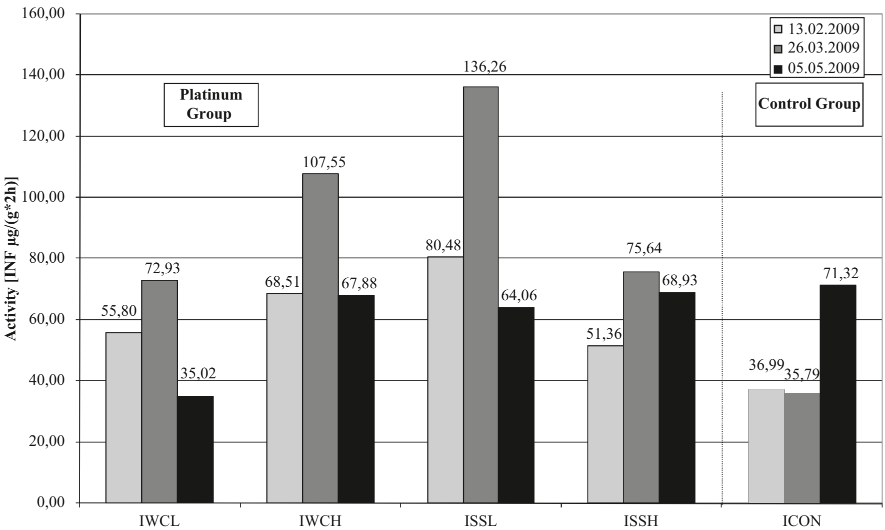

Fig. 5.4 Field test: quality change of microbiological activity in platinum soil with different fertilizers

different ameliorants after a short time. After only two months, the microbiological activity increased by 57% from 68.51 to 107.55 [INF µg/(g*2h)] (Fig. 5.4) with an addition of 5% in the matured sewage sludge. After four months, the initial growth spurt dropped off in almost all test groups. Only the plants with 15% matured sewage sludge (ISSH) performed well in terms of microbiological activity. Activity decreased compared to two months earlier but increased by 34.2% compared with the initial microbiological activity. Against all expectations, the control trees without any ameliorant showed an increase in the microbiological activity of 92.8% compared to the beginning of the trial.

5.3.4 Total Quality

To get a better overview of change in tailings quality, the visual appearance of the plants, the soil quality and the microbiological activity were monitored over a total period of six months. The same tree species as used in the laboratory trials was monitored in field trials under near-natural conditions using similar ameliorants. Only the total impact of the whole environment can give a reliable indication of change in quality of tailings. In the laboratory trial, the trees grow best in gold and platinum tailings to which the matured sewage sludge ameliorant was added, while soil quality improved most in the tailings material ameliorated with the addition of woodchips. In terms of microbiological activity, the matured sewage sludge worked best in gold tailings and woodchips in platinum tailings. The total quality of all different sources of impact gives a clear indication of quality change in the monitored soil. Both types of tailings, gold and platinum, showed increased plant growth, improved microbiological activity and a better chemical quality after adding the pre-treated ameliorants. The selected tree *Searsia lancea* adapted to the specific conditions of polluted tailings after replanting and controlled irrigation showed a spurt in growth and assisted in the change in soil quality. These results of the controlled laboratory and field experiments indicate a clear success and should be considered in the closure plan of both gold and platinum tailings storage facilities.

5.4 Conclusions

The growth of the trees and the microbiological activity of the soils showed a clear improvement in tailings quality after using ameliorants. The quality of both types of polluted tailings, platinum and gold, could be improved, as demonstrated by chemical analysis, so that the tree *Searsia lancea* was able to grow well. Two of the ameliorants—woodchips and matured sewage sludge—were able to bind and immobilise some of the heavy metals and sulphate and release enough nutrients to support the plant in active growth. The introduction of these tree species to the different tailings showed a utilization of pollutants and an improvement of soil quality. This is the benefit of the tree metabolism combined with immobilizing pollutants and not a result of leaching of pollutants. Finally, this application was an attempt to rehabilitate and to find a basic use for polluted tailings as an area for landscaping and reforestation and possibly also for agriculture. While reforestation obviates sandstorms, it also creates a new resource for energy, firewood or furniture—a reusable raw material—and influences the climate change by reducing green house gases. After a few years of detoxification, treated tailings could possibly also be used as land for agriculture as well, but for this purpose soil quality and the immobility of the pollutants must be guaranteed.

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Chapter 6
A Policy Framework for Sustainable Utilisation of Farmland for the Waterberg District Municipality in South Africa

Charles Nhemachena, James Chakwizira, Mac Mashiri and Sipho Dube

Abstract This study crafts a policy framework for sustainable utilisation of farmland for the Waterberg District Municipality in South Africa. The district, being predominantly agricultural and rural, faces contention in terms of land allocation for traditional agricultural land uses versus contemporary uses such as golf courses, game ranching and holiday accommodation/lodges. The situation was exacerbated by the fact that these challenges were besetting the district at a time when it did not have a policy for sustainable land use. Fully cognisant of this shortcoming, the municipality decided to generate a policy framework for sustainable utilisation of farmland. The approach entailed a participatory situational analysis identifying all land zones for agricultural purposes in the district and prime agricultural land as well as environmentally sensitive areas. In addition, the policy environment governing the development of agricultural land was thoroughly assessed to ensure compliance, consistency and alignment of the policy with the provincial and national policies. The outcome is a policy framework expected to facilitate, guide and influence the sustainable subdivision of farmland taking into account the realities of the existence of competing needs for agricultural land use. The policy framework clearly shows specific areas that may and may not subdivide further, with reasons. Also, it presents a set of guidelines and minimum requirements, to inform decision-making regarding subdivision proposals.

Keywords Land policy • Sustainable • Farmland • Waterberg • South Africa

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6.1 Introduction and Background

"Land is an asset. Land is scarce. Land is fragile." These statements reflect the basic relationships of humankind with land: social, economic and environmental. Humanity's association with land springs from the enduring nature of land: it is the basis of food, shelter and livelihoods (Ministry of Agriculture and Land Affairs 2001). It is no exaggeration to say that sustainable utilisation of land resources is pivotal to the economic, social and environmental future of the economy. Furthermore, high potential and unique agricultural land is likely a non-renewable asset, and its preservation is fundamental to achieving sustainable resource management, including sustainable use of agricultural land (Department of Agriculture 2006).

An increasing trend of subdividing productive agricultural land in the Waterberg District Municipality (WDM) has been witnessed in recent years. Most of the subdivisions have been executed without public interest, participation and assessment of the costs and benefits leaving the district with little productive land for agricultural development (Waterberg District Municipality 2008a). In a bid to promote balanced sustainable development, WDM resolved that generating a policy framework to guide the subdivision of agricultural land was necessary. Such a policy framework would further assist the district and local municipalities in developing by-laws vital in executing the intentions of each municipality's respective relevant land use schemes.

The overarching strategic policy objectives and rationale for the study and development of a policy framework for sustainable utilisation of farmland in the Waterberg District Municipality were to: (a) preserve agricultural land in WDM as enshrined in the Subdivision of Agricultural Land Act (1970) (Act No 70 of 1970), the Conservation of Agricultural Resources Act (1983) (Act No 43 of 1983) and Department of Agriculture (2006) National Policy on the Preservation of High Potential and Unique Agricultural Land and; (b) provide guidelines relating to norms and standards applicable in the adjudication of applications for: subdivision of agricultural land, change of agricultural land, and rezoning and conversion of agricultural land.

6.2 Conceptual Framework

Many human cultures have lived in harmony with diverse agro-ecological environments for centuries (Pontius and Schneider 2001; Perman et al. 2003). Many others have incidentally failed to live in harmony with the mundane agro-ecological environments, resulting in such problems as loss of biodiversity, climate change, food shortages, hunger, starvation, poverty, inequality, drainage or severe impact of wetlands, and soil erosion throughout the world (Parmesan and Yohe 2003; Leemans and Eickhout 2004; Rong and Futian 2007). Conservation of environments, habitats, ecosystems and wetlands needs to be a priority given the governance of cultural and ecological values enshrined and protected (Altieri 1999; Knill and Lenshow 2000; Moss 2004). But a more optimistic note is that large-scale restoration and recreation of habitats, ecosystems, wetlands and riverine systems is beginning to happen throughout the world through ecological engineering and diversified economic pathways opportunities (Dasgupta et al. 2000; Rabalais et al. 2002).

One of the requirements of sustainable utilisation of resources is the efficiency of intergenerational allocation that is important to the long-term utilisation of resources (Rong and Futian 2007). Marsden et al. (2001) argues for the need to reconstitute nature through rural development practices by way of realignment of social theory and empirical practice in considering the real potentiality of alternative and emergent rural development cases.

Ellis and Biggs (2001) argue that if a new paradigm of rural development is to emerge, it will be one in which agriculture takes place along with a host of other actual and potential rural and non-rural activities that are important to the construction of viable rural livelihoods, without undue preference being given to farming as the unique solution to rural poverty (Bilsborrow and Ogendo 1992; Kline and Ralph 1999; Kohler 2000). This paper focuses on a multi-disciplinary approach to addressing sustainable utilisation of farmland in the Waterberg District Municipality.

6.3 Study Area

The WDM (Fig. 6.1) is located in the western section of the Limpopo Province sharing the provincial border with Botswana. Within the province, Waterberg shares its borders with Capricorn and Sekhukhune District Municipalities. The southern boundary of the district abuts Northwest Province and Gauteng Province.

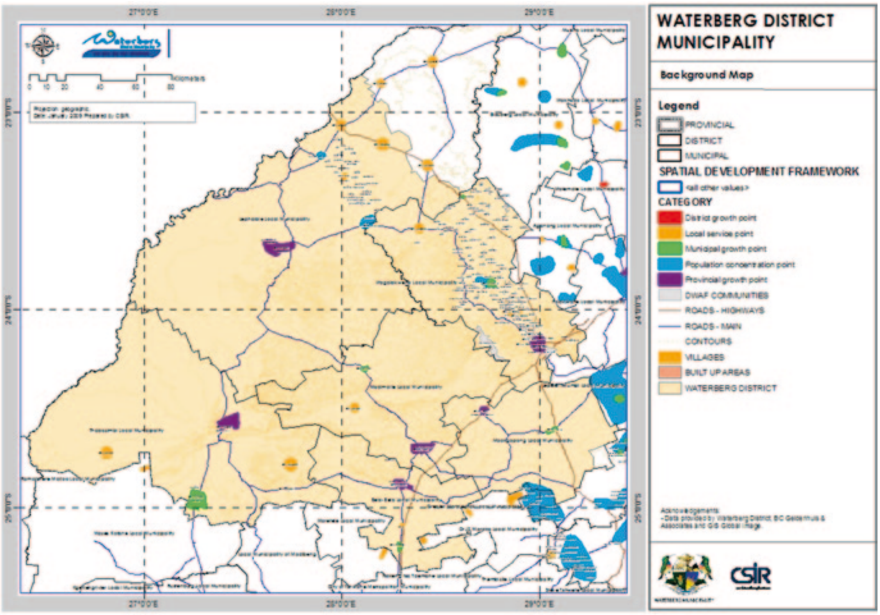

Fig. 6.1 Background map of the Waterberg District Municipality

Waterberg District consists of six local municipalities: Bela-Bela, Modimolle, Mogalakwena, Mookgopong, Lephalale and Thabazimbi. Compared with the rest of the province, Waterberg is unique as it encompasses little former homeland area and has an internationally acclaimed biosphere making up 15% of its total area. This creates its own set of challenges and opportunities. Waterberg consists mainly of commercial farms, game farming and only approximately 0.54% of the total area is used for settlement purposes (both towns and villages) (Waterberg District Municipality 2008a; Waterberg Spatial Development Framework-SDF 2009).

6.4 Study Methodology

The process of drafting the Waterberg District land policy framework was conducted through official consultation and stakeholder participation at all levels of the political economy impacting and impacted by WDM. A broad consensus emerged not only on the need for urgency in policy development but also on the critical issues that process should address. A number of sequential processes were adopted and satisfied. These entailed a comprehensive review of available literature (existing agricultural reports, Integrated Development Plans (IDPs), Spatial Development Frameworks (SDFs), legislative documents), preparation and revision of several drafts, discussion of drafts with civil society groups, the private sector, owners and users of land and various government agencies (Nhemachena et al. 2009a). The penultimate version of the policy was presented to a District Planning Forum before transmission of the final draft to the District for approval. Figure 6.2 is a graphical representation of the study methodology.

6.5 Results and Discussion

6.5.1 Situational Analysis of the Agricultural and Related Environment

This section presents the major highlights of results from the situational analysis of the agricultural and environment of WDM (Nhemachena et al. 2009a).

Legislative framework The generated policy framework recognises the existence of other legislations that have a direct or an indirect bearing on the access to and utilisation of agricultural land, including, but not limited to: Development Facilitation Act (1995) (Act 67 of 1995); National Environmental Management Act (1998) (Act 107 of 1998); Local Government Municipal Systems Act (2000) (Act 32 of 2000); Land Use Management Bill (2004); National Policy on the Preservation of High Potential and Unique Agricultural Land 2006 and various provincial ordinances. The study confirmed the findings of the National Policy

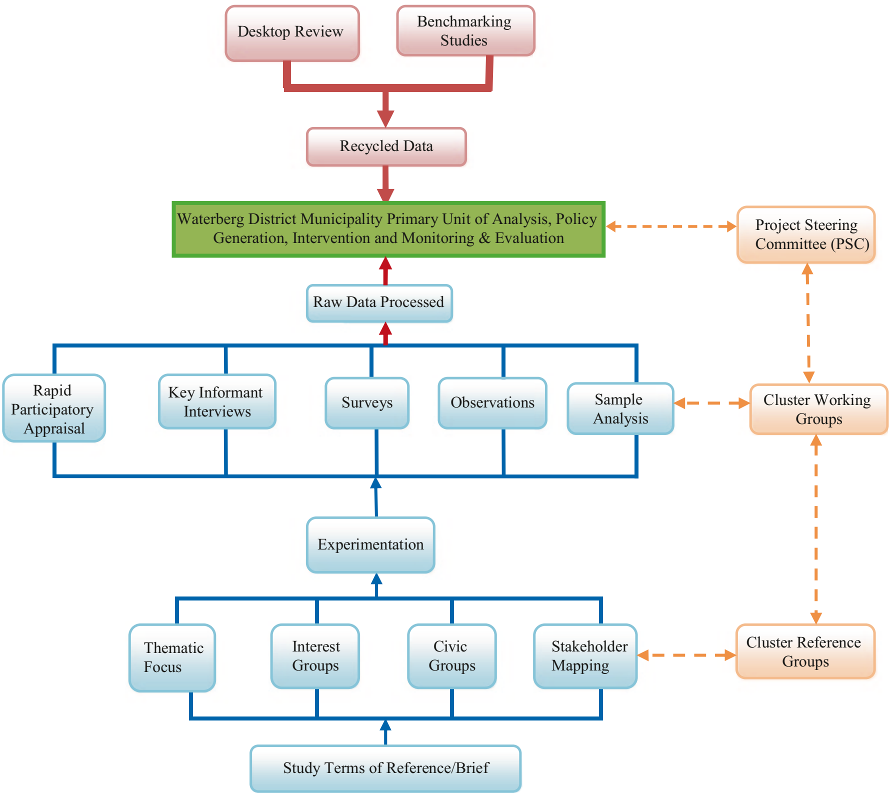

Fig. 6.2 Study methodology

on the Preservation of High Potential and Unique Agricultural Land (Department of Agriculture 2006) including a summary of some of the legislative and administrative flaws that emerged in the administration and implementation of the Subdivision of Agricultural Act (1970) (Act 70 of 1970). These are summarised in Table 6.1.

Importance of land policy for agricultural land use management and development The WDM land policy framework for agricultural land-use management is guided by two main underlying rationales. Firstly, there is the widely perceived resistance to the idea of uncontrolled agricultural land development. Secondly, there is the commonly expressed preference in particular sectors of society to promote a healthy mix of various types of desirable agricultural land development, urban development and meeting the requirements of sustainable environments (Ministry of Agriculture and Land Affairs 2001). The *resistance to uncontrolled development* is motivated by a number of concerns, the precise mix of which is determined by the particular social, economic and political contexts of different times and places. Some of the reasons include the ones summarised in Table 6.2. Also, the *wish to*

Table 6.1 Sustainable utilisation of agricultural land gaps and shortcomings

Physical and spatial bottlenecks	Agricultural impediments	Legislative constraints	Political challenges
Inadequate and inappropriate control, protection and regulation of the available high potential and unique agricultural land Absence of uniform guidelines for use by local authorities in the development and review of their SDFs and IDPs Increase in the proliferation of land use changes, rezoning and subdivision of agricultural land which take place without approval	Absence of refined agricultural subdivision norms and standards to appropriately guide decision-making on agricultural land use related matters	Fragmentation and multiple statues applicable to agricultural land make planning, management and sustainability of the sector a challenging task A number of land use related legislations (e.g. Development Facilitation Act (DFA), Draft LUMS, etc.) which are administered by other departments and/or spheres of government, place a direct and indirect demand on agricultural land for non-agricultural development	Adjudication over land development applications on agricultural land is not uniform and consistent at all levels of decision-making

Table 6.2 Reasons for controlling agricultural land use and development

Environmental concerns	Efficiency of infrastructure provision and traffic management	Social control	Health and safety concerns	Aesthetic concerns
Uncontrolled development of agricultural land can have adverse effects on natural habitats, cultural landscapes, and air and water quality	Infrastructure capacity constraints presented in a context where development permits are granted without assessing critically the capacity of existing infrastructure to accommodate the new developments The concomitant challenge regarding infrastructure that is provided, generally at high financial cost, without taking into account the opportunity cost of these new developments in terms of the societal impact on land-use and settlement patterns for example	Controlling agricultural land uses and building types has long been a means of exerting social control, particularly through the exclusion of certain types of person, household or economic activity from certain areas through the application of particular development controls limiting, for instance, plot sizes, plot coverage and home industries	Uncontrolled development can lead to overcrowding and unsafe building construction Certain agricultural land use and development decisions can also be detrimental to the health and safety of neighbours	Controlling and regulating agricultural land development enables the district to prescribe certain design parameters for buildings

promote desirable development is driven by a number of different concerns that relate mainly to land management and development.

Subdivision of productive agricultural land has become a trend in recent years Most of the land and agricultural subdivisions have been executed in the absence of clear guiding principles and regulations (Waterberg District Municipality 2008a). Consequently, land and subdivision suitability assessments criteria including auditing the public and environmental benefits and costs of proposed land and subdivision developments have been in most cases not considered at all.

The distribution and demography of the population has implications for land and agricultural use policy and decisions In the study area, such densely populated areas as Mogalakwena exert pressure for the provision of engineering services and socio-economic developments to meet the growing needs and demands of such spatial areas. Twenty percent of all people in the district area reside on farms; 39% in formal towns; 2% in informal settlements and 39% in tribal areas (Waterberg District Municipality 2008a; Mogalakwena Local Municipality 2008). Pro-active and strategic forward planning of regulation, managing and sustaining the competing and often conflicting land and agriculture development interests is therefore a vital component of the growth and development trajectory in the district.

Agriculture profile of the district and continued dependence on food imports despite the inherent local agricultural production potential Despite the high agricultural production potential, agriculture continues to contribute only 3.6% towards the economy of WDM (Waterberg District Municipality 2005, 2007, 2008a; Waterberg SDF 2009). Many local municipalities in the district continue to import agricultural products outside their boundaries despite this potential, perhaps a worrisome trend and cause for concern. This trend is probably explained by a combination of factors some enumerated in the Waterberg IDP (Waterberg District Municipality 2008a). These range from generally low levels of development in the area that is manifested in terms of high levels of poverty. In addition, poor land and agriculture infrastructural development further inhibits the growth and development potential. This may suggest strongly that potential and emerging farmers have limited access to resources necessary for enhanced production.

Relative importance of land and agriculture in local economic growth and development Although agricultural development is not as dominant in terms of its contribution to the Gross Value Added of the region, it remains a critical base for livelihood sustenance of the majority of the people especially from the previously disadvantaged sections of the society (Waterberg District Municipality 2005). Also, land and agriculture forms an integral backbone for providing basic infrastructure, facilities and amenities that support and promote eco-tourism (incidentally a vital component of the district economy; Waterberg District Municipality 2005, 2007, 2008a, b).

Soil potential and land capability assessment indicates that high potential areas for crop farming are limited Ranching potential, however, is widespread and conservation outside the proclaimed nature reserves is limited to eco-tourism activities on

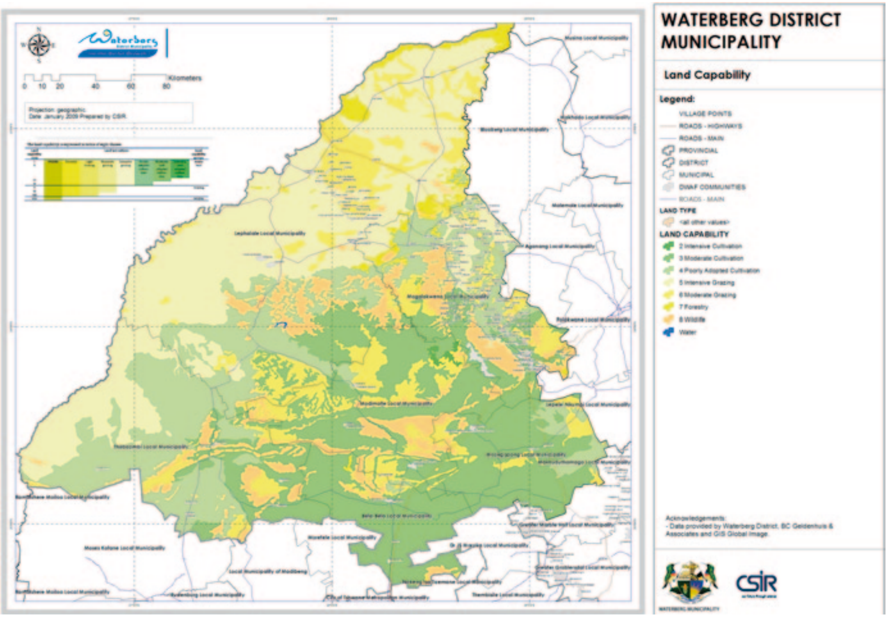

Fig. 6.3 Land capability map

commercial farms. The scope for maximising on this opportunity should be tapped. Figure 6.3 presents a land capability map for WDM.

Land reform issues Within WDM land reform issues encompass a complex array of challenges located within the sphere of land access, land tenure, land restitution (land claims) and land administration. The key challenge for the district in the land reform process is to effectively deal with the injustices of land dispossession, equitable land distribution in terms of ownership, reduction of poverty and economic growth, tenure security as well as a system of land management which will support sustainable land use patterns. Land restitution and land redistribution of which the potential impact is yet unknown could alter the spatial pattern and land needed for various macro land uses (e.g. settlement development, agricultural development, mining, conservation areas) enormously.

Based on the situational analysis (Nhemachena et al. 2009a) and stakeholder engagements, one could postulate that the land restitution process could potentially witness many people obtaining access to land that could result in improved living standards and quality of life (provided adequate training and support systems are established for the programme). At the same time, the land restitution process could unfortunately result in large-scale sterilisation of economically productive land (e.g. including high potential agricultural land, mining of certain minerals, and nature conservation areas) if not managed and planned within the context of a spatial development framework, land and agricultural subdivision policy framework and guidelines that considers all these factors. Land claims are mainly concentrated in the Mogalakwena and Lephalale Local Municipalities. These are also the areas with the highest population densities and as indicated earlier this emanates from the historical background of the areas (Waterberg District Municipality 2008b).

Environmentally sensitive areas Several areas in Waterberg have been identified as habitats of rare and threatened animal and plants species. These areas largely coincide with the biosphere reserve and existing conservation areas. These areas are highly vulnerable to the large-scale disturbances of mining and urban activities (Waterberg District Municipality 2008a, b). Ring fencing and sterilising these areas to land and agriculture subdivision is necessary with exploitation permitted under special consent.

The Waterberg Biosphere Reserve (Fig. 6.4) constitutes an environmentally unique area that might be negatively affected by human activities that physically change the environment. The Waterberg Biosphere Reserve established in 2001 is one of the only five biospheres in South Africa. The biosphere consists of three distinct zones: the biosphere core (114,571 ha); the buffer zone (150,000 ha) and a transition zone (15,0000 ha). The core area constitutes proclaimed nature reserves with the buffer and transition zones filling the areas in between (Waterberg District Municipality 2008a, b).

The biosphere is sensitive to urban, rural and mining activities but provides opportunities for ranching and conservation activities (Waterberg District Municipality 2008a; Waterberg SDF 2009). It is critical that any developments in and around

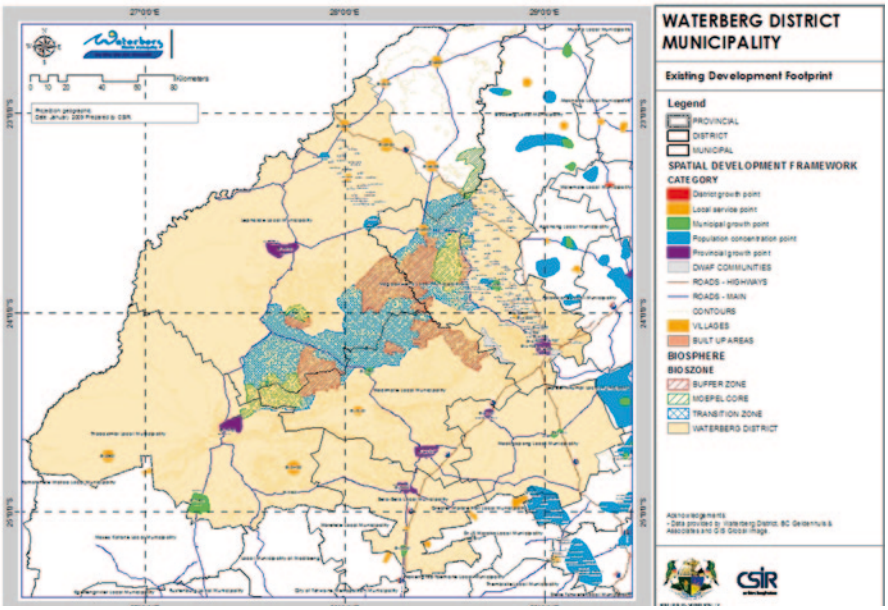

Fig. 6.4 The Waterberg biosphere reserve

Table 6.3 Departure points for land and agriculture subdivision policy framework development

Achieving the right mix of development	Food security and household productivity	Farmer productivity strengthening model
Development proposals should aim to achieve the correct balance between economic development, sustainable resource use and protection of natural resources	High potential agricultural land irrespective of existing use (i.e. whether it is cash crop farming or not) should be protected against future agriculture productivity sterilization from settlement development or any alternative land uses Township development at existing nodes (including future proposed nodes) should take full cognisance and be sensitive to high potential agricultural land Household food production is seen as a means of improving food security and fighting poverty through utilising agricultural resources within the vicinity of communities	Commercial agriculture contributes significantly to the district's economy and requires interventions, which create an enabling environment in which both established farmers and emerging commercial farmers can thrive and develop Improved institutional co-ordination of activities, interventions, programmes and projects is a key issue for improved delivery and successful development of the agriculture sector in the Waterberg District Municipality

the biosphere clearly distinguish high conservation potential areas, middle conservation areas and development nodes, e.g. in transitional zones. In addition, the density of developments that should be allowed across the biosphere need to be clearly identified and set out to ensure that environmentally sensitive and conservation areas are protected.

Departure points for land and agriculture subdivision policy directions Based on existing land and agriculture document analysis and reviews (Nhemachena et al. 2009a), fieldwork observation and measurements, geographical information systems analysis (including climatic, soil, hydrological, physical, and geological analysis), it is argued that it is imperative to have a land and agriculture subdivision policy for sustainable utilisation of agricultural and farmland in WDM. The policy framework departure points are summarised in Table 6.3.

6.5.2 *Policy Framework Issues and Guidelines*

The decisions of planning authorities, whether related to the formulation of plans such as IDPs or the consideration of land development applications, must all be consistent with the vision, objectives, principles, norms and standards as developed and generated in the sustainable utilisation of farmland policy document (Nhemachena et al. 2009b). The sustainable utilisation of farmland policy objectives, principles and norms and highlight of specific policy position is summarised in Table 6.4.

Table 6.4 Sample representation of some issues tackled by the sustainable utilisation of farmland policy in Waterberg District

Strategic vision					
To effectively, efficiently and continuously promote and sustain the long term future development, use and management of agriculture farmland, biosphere, mining and human settlements in the district					
Policy objectives					
Ensure that high potential and unique agricultural land is used primarily for agricultural purposes to enhance food security	Provide user friendly guidelines for agricultural land use changes as well as subdivision of agricultural land	Regulate and control access to agricultural land by proponents of non-agricultural development	Preserve agricultural land resources for the benefit of communities whose livelihood is based on agriculture for: income generation, food security, job opportunities and better quality of life	Promote knowledge and enhance skills transfer amongst stakeholders on matters pertinent to land use planning in general and preservation of agricultural land in particular	
Principles, norms and standards					
Sustainability	Equality	Efficiency	Fairness	Good governance	
Broad strategic policy intervention levers and areas					
Providing a definition of agriculture and farmland use that distinguishes agriculture land uses and activities from non-agricultural land uses and activities in WDM including defining what a farm unit is	Balancing environmental protection, agricultural exploitation needs with growth and development concerns in WDM	Generating specific types/classes of agricultural commercial and industrial uses (including farm-related industries) that are freely permitted in agricultural and farm lands in WDM, lodges, etc	Promoting balanced and sustainable environmental development, management of the natural environment and the biosphere in WDM	Guidance and direction in terms of the provision and delivery of community facilities and infrastructure in agricultural and farmland communities and areas	Outlining development and provision of holiday accommodation on farmlands and agricultural areas guideline

Table 6.4 (continued)

Example of specific provision to address the broad strategic policy intervention levers and areas: providing a definition of agriculture and farmland use that distinguishes agriculture land uses and activities from non-agricultural land uses and activities in WDM including defining what a farm unit is				
Inclusive definition of agriculture and farmland use/activities accommodative of all farming types such as: industrial and commercial activities which are primarily related to agriculture, natural features that enhance the area for agriculture and ecosystem health and sustainable agricultural practices that promote a healthy environment has been incorporated	The farm unit should consists of: land base, barns and other buildings that support the farm operation, farm dwelling and temporary dwellings required for additional labour or for a retiring farmer	One residence/dwelling unit may be built on the agricultural farm premises where it is an accessory to a commercial scale farming operation	A second permanent dwelling on a farm or on a separated lot will not be permitted. Two additional units may be allowed at a density of 1 unit per 10 ha that could be used for guest accommodation. Clustering of buildings should be regarded as a high priority	Agri-villages establishment will be supported if it is in support of agricultural production and providing security of tenure to farm workers. The criteria that should be used in evaluating agri-village applications should include but not be restricted to the following: • Why farm worker housing cannot be provided in an urban area, before an agri-village can be established outside of existing nodes. • Agri-villages must be identified as a node in SDF. • Agri-villages should be within walking distance (less than 2 km). • Agri-villages should preferably be established on existing disturbed sites. • Agri-villages should be of limited population size (usually up to 500 people)

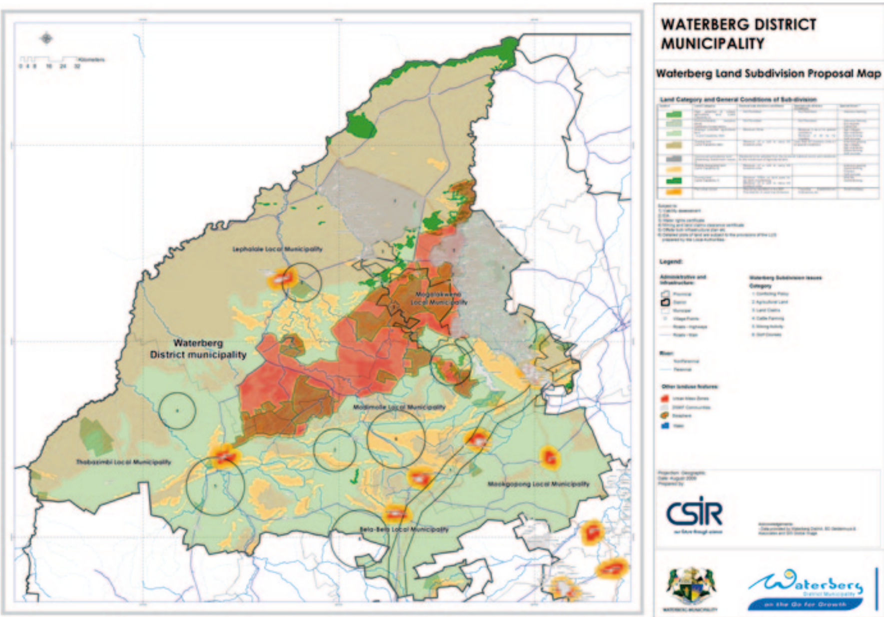

Fig. 6.5 Waterberg District subdivision of farmland issues and proposals

While Table 6.4 presents a snapshot of the policy document, the actual policy document itself is more extensive and provides clear policy direction and guidance regarding density, accessibility, siting/location, design, materials and aesthetics regarding developments in the area. This covers for such a range of activities as establishing holiday accommodation and lodges, developing cable cars in the biosphere, establishing agricultural factories on farmlands, bush pubs and conferencing facilities and infrastructure, handling home industries and home occupations, extraction and mining of pit and river sand in agricultural premises, greenhouse development and management, game farming infrastructure and development (Nhemachena et al. 2009b). Figure 6.5 presents WDM land subdivision proposals based on the above information.

6.6 Conclusions

The useful outcome of this study is a policy framework expected to facilitate, guide and influence the sustainable subdivision of farmland taking into account the realities of the existence of competing needs for agricultural land use. The generated policy framework shows clearly specific areas that may and may not subdivide further, with reasons. Also, it presents a set of guidelines and minimum requirements, to inform decision-making regarding subdivision proposals.

6.6.1 Recommendations

Generally, policy frameworks—such as the Subdivision of Agricultural Land Act (1970, Act No 70), the Conservation of Agricultural Resources Act (1983, Act No 43) and the Department of Agriculture (2006) National Policy on the Preservation of High Potential and Unique Agricultural Land—for sustainable utilisation of farmland should incorporate the following issues:

- The policy framework should be informed by an extensive agricultural environmental analysis supported with empirical evidence and insight into existing and potential agricultural land uses in the district.
- It is important to establish a baseline for systematic control, protection and regulation of available high potential and unique agricultural land as defined by stakeholders.
- A set of uniform guidelines should be generated to be used by local authorities in the development and review of their spatial development plans. The spatial development plans that will require updating to incorporate sustainable farmland utilisation requirements include the Spatial Development Framework (SDFs), Integrated Development Plans (IDPs), Town Planning Schemes (TPS), Master Plans (MP), Physical Plans (PP) and Land Use Schemes (LUS).
- It is also important to establish an appropriate policy framework for better tracking and management of agricultural farmland land use migration trends and changes, rezoning and subdivision so that planning becomes pro-active rather than reactive.
- Establishing an agricultural farmland databank is also one way of improving the agricultural information management systems.
- The final policy documents, including the translations into the major indigenous languages of the people in the affected areas, should be disseminated as widely as possible using different media.
- Inclusive and participatory approaches are important to allow various agricultural participants, experts, beneficiaries, users and interest groups to provide input and own the process and product.
- A strong capacity building and training programme should be factored as part of marketing and implementing the policy. This will need to be extensive and cover all levels of government and segments of society.
- The policy is never complete unless a robust implementation plan including specific projects, budgets, timelines and project champions has been clearly spelt out. A clear implementation framework, structure and plan are crucial to ensure that the good policies contained in the policy document are transformed into real projects that make a difference in people lives.

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Chapter 7
The Zooecological Remediation of Technogen Faulted Soil in the Industrial Region of the Ukraine Steppe Zone

Yuriy Kul'bachko, Iryna Loza, Olexandr Pakhomov and Oleg Didur

Abstract This paper is devoted to research in the field of mining operations. Under the conditions of Ukraine's steppe zone the extraction of minerals is important. To minimize the consequences of coal mining, the disturbed soils were re-cultivated, thus minimizing the effect of toxic compounds, which are contained in mining rock, on human beings and the majority of soil biota representatives and it was taken care that these compounds do not get into the rehabilitated soil. This research focuses on the vitality of rehabilitated soil as a sustainable agricultural system. Earthworms (*Lumbricidae*) are the primary decomposers of organic material; their role in soils is to improve natural soil and/or artificially created soil. This paper studies the possible influence of different variants of substrates used in re-cultivating the representatives of soil saprophages.

Keywords Biomass • Mining Remediation • Sustainable Agriculture • Humidity • Earthworms

7.1 Introduction

When deciding fundamental issues of the mutual relation between human beings and the environment, it is necessary to develop a scientific basis for the creation of new optimal artificial landscapes (Zonn and Travleev 1989) favorable for the existence of biota. Of particular interest is the rehabilitation of degraded soil when creating steady artificial biogeocenos, the integral parts of which are soil invertebrates (Travleev et al. 1988; Grytsan 2000; Kondratyuk 1980). They are present in

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practically every lot of forest and re-cultivated agricultural lands. The organizational and functional structure influences the formation of vegetation and the stability of the whole artificial ecosystem.

The extraction of minerals is important for the highly industrial regions of Ukraine. The Western Donbass is one of the most environmentally degraded regions of Ukraine, with an area of 12,500 km^2. It has about 25 billion t of coal reserves, which run under the Samara River basin at depths of 200–700 m (Zwerkovsky 1997). Following mining, subsidence, equivalent to about 90% of the depth of the extracted layer, is common and large areas become flooded. By-products of the coal mining (toxic water-soluble salts, compounds of heavy metals) negatively influence the environment and reduce the utilization of soils for agricultural activities (Loza and Nazarenko 2006).

The steppe zone of Ukraine is situated in a temperate continental climate area where moisture is one of the main limiting factors (Belgard 1971). The soil covering in the Dnepropetrovsk region is heterogeneous. This is caused by the difference in the climate, geomorphological features, and other natural factors. A total of 277 soil types have been defined in the region (Soils of the Dnepropetrovsk region 1966). Ordinary medium-power, low-humus chernozems (according to the classification of WRB, Chernozems Calcic) prevail. They occupy the greatest part of the territory and contain 4–5% of humus. Chernozems are highly productive soils on which the majority of agricultural crops grow (World Reference Base for Soil Resources 1994; Polupan et al. 2005). The re-cultivated agricultural areas represent the high-water bed of the Samara River, where prospective variants of remediation of the degraded soil are used. The remediation includes application of a 50-cm layer of loess loam and 50–70 cm of bulk chernozem on the true surface of mining spoil. This spoil is piled up by the mine spoil which is clay mass with impurities in coal and pyrite, with a large amount of toxic compounds for biota. The advantage of applying a 50-cm layer of loess loam is related to its role in protecting newly made soil and the ecological profile from the vertical movement of toxic salts and heavy metals (Kharytonov et al. 2005; Kharytonov and Zhilenko 2006).

The main purpose of re-cultivation is the rehabilitation of degraded territories, where the creation of highly productive plantation possessing high environmental converting properties is possible (Zwerkovsky 1999; Grytsan 2000). For this purpose, it is necessary to present all the ecosystem components—green, soil, microbiocenosis, and animals. Soil-dwelling animals promote the improvement of ecological properties of soil (Edwards and Baker 1992; Makeschin 1997). Due to the various structural and functional characteristics, they are involved in the optimization of all ecosystems, including agrocenosis, and in the increasing of productivity (Andren and Lagerlof 1983; Meier et al. 1997). The involvement of various taxons of animals in improving the soil structure, improving agrochemical characteristics, decomposition of plant residues, and transformation of organic substance, is a preliminary condition for the steady functioning of artificial ecosystems. Various groups of saprophages react similar to the use of mining solid as a substratum during remediation. If only a small amount of mine solid is used, animals adapt; however, when large amounts (more than 40% of gross weight substrates) are used, the living parameters of soil animals decrease dramatically and the integrated parameters of the ecosystem are impaired (Pakhomov et al. 2009).

In the improvement of the structural and chemical composition of soil, soil saprophages, especially earthworms, play a major role (Vsevolodova-Perel 1997; Giliarov and Striganova 1978). The high plasticity of this group of animals, the trophic activity, and involvement in the soil formation quite often has decisive importance for soil preservation (Zrazhevsky 1957; Ivantsiv et al. 2002). This is especially important when making artificial soil. The study of Kul'bachko et al. (2008) found that the presence of animal saprophages in artificial, mixed soils promotes more intensive evolution of carbon dioxide gas as one of the most important characteristics of soil bioactivity. The mining spoil, yet, negatively influences the parameters of soil aeration.

Among abiotic factors, temperature and humidity significantly influence the existence of soil invertebrates. They are the major ecological factors, particularly in the life of earthworms (Atlavinite 1982).

In severe climatic conditions, steppe protective forest belts serve as concentrators of biodiversity. This is why it was necessary to find a different type of wood planting to optimize the formation and sustain the existence of soil saprophage communities. Under steppe conditions, remediation using some tree species (i.e., eastern redcedar, Bosnian maple, and false acacia) is best-known (Zwerkovsky 1999).

When re-cultivating soil, it is difficult to predict the state of the artificial ecosystem and the biota. In order to investigate this problem, laboratory research is necessary, which would show the effect of variant fillings from the artificial, mixed soils and also show its effect on growth and development of plants and animals.

7.2 Material and Methods

The research subjects were earthworms (*Lumbricidae*). The purpose of the research is to determine the change in biomass of the representatives of decomposers for vegetational tree waste on different variants of artificial soil substrates.

To study the reaction of earthworms to environmental factors, we used the mathematical theory of planning and modeling of complex systems (Nalymov 1971; Tomashevskiy 2005). The experimental design was the standard Latin square, explained in Table 7.1.

Trials were established in culture containers (square, 201 cm^2) and the substrate served as the habitat for the research subjects. The air-dry mass of each substrate in

Table 7.1 Scheme of the standard Latin square 3 × 3

B	A		
	a_1	a_2	a_3
b_1	c_1	c_2	c_3
b_2	c_2	c_3	c_1
b_3	c_3	c_1	c_2

the trials was 700 g. The substrate was covered with foliage litter of the specified wood (50 g per culture box). Then ten animals were placed in each culture container. The starting weight of the animals was fixed.

In the laboratory where the pot trials were performed, the temperature was maintained within the limits of 20–22ºC, and precipitation of different amounts was simulated. Distilled water was used for watering in the experiments. The duration of the experiments was 30 days.

To solve the set problem, we have chosen the following conditions for the experiment:

- Factor *A* (*form of bulk substrate*). Levels of factor *A* are as follows:
  - Mine spoil a_1 with $pH_{aquas} = 3.5$; solid = 0.60%
  - Chernozem a_2 with $pH_{aquas} = 7.0$; solid = 0.05%
  - Light loam a_3 with $pH_{aquas} = 7.5$; solid = 0.065%
- Factor *B* (*species belonging of litter*). Levels of factor *B* are as follows:
  - Eastern redcedar (*Juniperus virginiana* L.) b_1 with $pH_{aquas\ (1:10)} = 7.2$
  - Bosnian maple (*Acer platanoides* L.) with $pH_{aquas\ (1:10)} = 5.9$
  - False acacia (*Robinia pseudoacacia* L.) with $pH_{aquas\ (1:10)} = 6.95$
- Factor *C* (*humidification*). Levels of factor *C* are as follows:
  - Epactal c_1 (40 mm/month)
  - Moderate c_2 (30 mm/month)
  - Weak c_3 (20 mm/month)

The chosen plan of experiment Latin square 3×3 is given in Table 7.2.

To determine the general direction of a shift for the studied characteristic, the criterion of sign test has been used (Lakin 1990).

The reaction of soil animals on the habitat conditions (i.e., physical and chemical characteristics) of the used substrates and litters is reported to be very important and influential; therefore we will consider the basic properties (Abrahamsen et al. 1980; Janssens de Bisthoven et al. 2005).

Table 7.2 The plan of experiment based on the Latin square with three fixed levels

Trial No.	Substarte (A)	Litter (B)	Humidification (C)
	Gradations of factor and the codes		
1	Mine spoil (1)	Redcedar (1)	Epactal (1)
2	Chernozem (2)	Redcedar (1)	Moderate (2)
3	Loam (3)	Redcedar (1)	Weak (3)
4	Mine spoil (1)	Maple (2)	Moderate (2)
5	Chernozem (2)	Maple (2)	Weak (3)
6	Loam (3)	Maple (2)	Epactal (1)
7	Mine spoil (1)	Robinia (3)	Weak (3)
8	Chernozem (2)	Robinia (3)	Epactal (1)
9	Loam (3)	Robinia (3)	Moderate (2)

The mine spoil is of grey color; when wetting, it gets the properties of structureless patching material containing small insertions of coal and occasionally pyrite. In the granulometric composition it relates to heavy silty-pulverescent loams. The absence of bivalent cations is a characteristic of the mine spoil. Considering the physical and chemical properties along with soil-water-air dynamics, it has been reported that mine spoil is not suitable to grow plants (Travleev et al. 1988, 2005; Masyuk 1988).

The samples of ordinary chernozem are presented by moderate and heavy silty-pulverescent loams with saturated bases up to 97%. In the composition of the soil-absorbing complex, Ca^{2+} and Mg^{2+}prevail up to 90% and 10%, respectively. The quantity of Na^{+} and K^{+} is low in the native ordinary chernozem. The percentage of humus in these soils is up to 4.0%.

With regard to the content of physical clay (up to 33%), the loess loam of pale-yellow coloration refers to light loams, and with regard to the prevailing fraction, it refers to silty-sandy ones (Masyuk 1989). The amount of humus from trace values ranges up to 0.9%. The effervescence from 10% of HCl is absent, which testifies to the absence of carbonates of calcium and magnesium.

7.3 Results and Discussion

Data on biomass of animals are given in Table 7.3. In the right-hand column average values of biomass change of the animals are indicated which reflect the difference between the biomass before and after the experiment.

The shift is the difference between the second and the first measurement. The typical shift is positive. The hypothesis that the biomass increase is the same before and after the experiment is rejected on the significance level exceeding a 5% bar-

Table 7.3 Conditions of planning and biomass change (Δ) of earthworms ($n = 10$ specimen/1 container) during one month

Container[a] number	Gradation of factor			$\Delta \pm m$ (g)
	Substrate	Litter	Watering	
1	1	1	1	1.32 ± 0.065
2	2	1	2	2.82 ± 0.40
3	3	1	3	1.30 ± 0.685
4	1	2	2	4.54 ± 0.37
5	2	2	3	4.31 ± 0.05
6	3	2	1	5.66 ± 0.18
7	1	3	3	−0.03 ± 0.74
8	2	3	1	5.66 ± 1.825
9	3	3	2	5.16 ± 1.865

m standard error of biomass change for each test

[a] There was a calculated average mass of 10 earthworms in each container. Then the difference between two average mean values of mass, namely before ($\overline{x}_1$) and after ($\overline{x}_2$) the experiment, was determined ($\Delta = \overline{x}_1 - \overline{x}_2$)

Table 7.4 Average values of biomass change for earthworms depending on gradation of factors (g)

Level of factor	Number of tests	$\Delta \pm m$ (g)
Litter		
Redcedar	6	1.81 ± 0.38
Maple	6	4.84 ± 0.28
Robinia	6	3.59 ± 1.35
Humidification		
Epactal	6	4.21 ± 1.03
Moderate	6	4.17 ± 0.67
Weak	6	1.86 ± 0.85
Substrate		
Mine spoil	6	1.94 ± 0.88
Chernozem	6	4.26 ± 0.71
Loam	6	4.04 ± 1.01

rier ($\alpha = 0.0004$). It may be approved with confidence that the statistically authentic "typical" shift towards the biomass increase of animals is observed.

The statistical analysis of permanent effects using dispersive analysis showed that these factors significantly influence the biomass of the representatives of *Lumbricidae*, with a *P* value of 0.022 for the influence of substrate, 0.008 for litter, and 0.017 for humidification.

The statistical analysis showed that juniper litter, weak humidification, and mine spoil had the lowest effect in increasing the biomass of earthworms, while a significant increase was noted in treatment with maple litter, epactal humidification, and chernozem (Table 7.4). The treatment of a layer of chernozem or loam on mine spoil can partially compensate for the negative influence on living organisms. Overall, the influence of chernozem showed the most positive ecological effect on the biomass of the soil animals. Treatments with false acacia tree waste causes slightly lower biomass when compared to that with maple tree waste; however, the effect of these two tree wastes exceeds significantly the effect of juniper tree waste. Therefore, it is expedient to use maple and false acacia plantings for remediation. Forest belts act as reserves for different representatives of soil saprophages and other animals involved in the ecological stabilization of the artificial ecosystems.

It is known that earthworms require sufficient humidification. The current study has shown that the highest values of worm biomass were reached with moderate and epactal humidification (from 30 up to 40 mm/month). Below this level the biomass of earthworms decreases dramatically from 4.17 to 1.86 g (Table 7.4). Forest plantings retain moisture in soil and serve as an additional source for moisture accumulation that favors the normal development of soil biota (Grytsan 2000). It is described by the change of microclimate in forest plantings when they are shading the soil and reducing the evaporation rate.

The results of paired comparison (according to the Duncan's Multiple Rank test) of all the processing methods are given in Table 7.5. With regard to the specified contrast pairs, the sign "<" shows that the average value of biomass of earthworms with the first method of processing in the experiment is less than the average value of biomass with that of the second.

Table 7.5 Pair comparisons of processing methods

Contrast		Statistical distinctions of effects
Substrate		
First method of processing	*Second method of processing*	
Mine spoil <	Chernozem	≤0.05
Mine spoil <	Loam	≤0.05
Chernozem <	Loam	None
Litter		
First method of processing	*Second method of processing*	
Redcedar <	Maple	≤0.05
Redcedar <	Robinia	≤0.05
Maple <	Robinia	None
Humidification		
First method of processing	*Second method of processing*	
Epactal <	Moderate	None
Weak <	Moderate	≤0.05
Weak <	Moderate	≤0.05

It is found that there is a statistically significant difference of the average biomass of earthworms in the following pairs: mine spoil < loam; mine spoil < chernozem; redcedar litter < maple litter; redcedar litter < robinia litter.

7.4 Conclusions

The main factor during remediation of the degraded soils is the creation of necessary conditions for soil biota, which are involved in the processes of optimization of ecosystems and improving their stability and productivity.

The present experiment proved that the change in the biomass of earthworms (*Lumbricidae*) depends on the species of substrate used, leaf litter of wood species applied, and humidification level. The analysis of the experiment data showed significant decrease in biomass of the representative of *Lumbricidae* at the presence of mine spoil, redcedar litter, and weak humidification. The biomass of earthworms increased when loam and chernozem were used as substrate, maple and false acacia as litter, and weak humidification was carried out.

This research assisted in finding the optimal variants for artificial, mixed soils and proved the normal existence of biological specimens. The amount of mine soil in the artificial soils should not exceed 40% of the general mass of substrate, because above this value the biomass of earthworms decreases dramatically and integral indices of the ecosystem become worse.

The presence of artificial forest belts on the re-cultivated territory influences the condition of soil biota positively. They act as reserve for the habitats; leaf tree waste is an important source for nutrition. Tree waste of redcedar is the least suitable for the nutrition of earthworms. Leaf tree wastes of Bosnia maple and false acacia are good food reserves for the nutrition of earthworms—we recommend these wood species for the creation of artificial forest belts on the territories of agricultural remediation.

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Chapter 8
Transcultural Gardens—A Proposal for Exploitation of Urban Voids as Intensively Productive Land and as a Method of Urbanization of Minorities: Case Studies Demonstrating Design Tools and Managing Methodology

Elina Karanastasi

Abstract This paper examines the introduction of urban agriculture as a medium for gradual urbanization, collaboration, exchange and identification of new multicultural urban inhabitants, especially immigrants originating from rural areas. The paper, after defining the state of urban agriculture for today's urbanism, examines the terms multiculturality, transculturality and multifunctionality in continuously productive urban voids and peri-urban areas. It also describes intercultural gardens in Germany, proposes the concept of transcultural gardens and presents six not yet realized projects in Greece.

Keywords Urban Voids • Urban Agriculture • Transculturality • Environmental Immigrants • Urban Gardens

8.1 Urban Agriculture as a Design Tool of Sustainable Development

Urban agriculture is the cultivation of land inside or in the limits of an urban entity (intra-urban agriculture or peri-urban agriculture). It has two main necessities today: the production of food; and the gradual urbanization of various minorities originating mostly from rural areas, in order to adapt to their new home.

According to the United Nations in 2040 63.8% of Earth's population and 83.7% of the developed countries' population will be urban citizens (United Nations, De-

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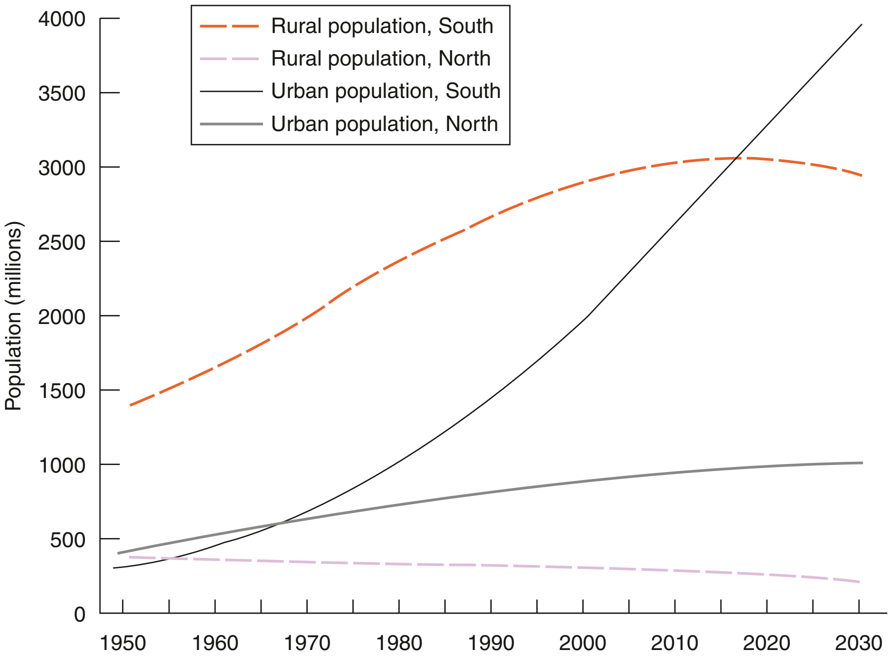


Fig. 8.1 Rural and urban populations in North and South, 1950 to 2030. (Source: UN 2004, from Mougeot 2006, p. 4)

partment of Economic and Social Affairs, Population Division, World Urbanization Prospects 2009), a fact that is most probably leading to urban poorness. Rural poorness is in fact a main reason of today's economical migration. Are we, therefore, coming to a dead end? What immigrants are now running away from, they are "causing" at new locations and settings (Fig. 8.1).

Urban agriculture is a sustainable development tool (Mougeot 2006), though it presupposes the cultivation, management and distribution of a variety of foods, the use or the reuse of resources, products and services that are found in nearby areas and the supply of these areas with products and services.[1] In this context, urban agriculture interacts with the urban ecosystem, uses the citizens as workforce, uses urban renewable energy sources (grey water, organic waste), has direct access to consumers, contributes to the urban greenscape and is influenced and directed by urban planning policies. Efforts have been made during the last few decades to bridge architecture and agriculture with designs for vertical farms that minimize urban land use.

Aspects of urban agriculture are not only ecological and economical, but also deeply social, with the example of community gardens and intercultural gardens.

[1] Definition: Luc Mougeot, International Development Research Centre. It is officially used by the UN-HABITAT Urban Management Programme, FAO, CIRAD.

Fig. 8.2 Master plan of the under study area of the old flea market in Neapolis Larissa in Greece with introduction of a bicycle network and a green grid (walking routes)

8.1.1 Examples of Design Proposals: Urban Agriculture in Dynamic Urban Voids

Architectural and urban competition Europan 7, runner up "The forest, the hairdresser, his mother and a roof", 2003. Urban design: Fuchs A., Karanastasi E. Consultants: Geerse A., Melenhorst M., Moelee M. A. (Figs. 8.2–8.8).

8.2 What is an Intercultural Garden?

Intercultural gardens began in 1995 in Goettingen, Germany (Móller 2001, p. 189) where a group of Bosnian women from a refugee centre recreated the orchard gardens of their home country. After the success of the first garden and the realization of a second one, an organization was formed in 1998 to manage and support

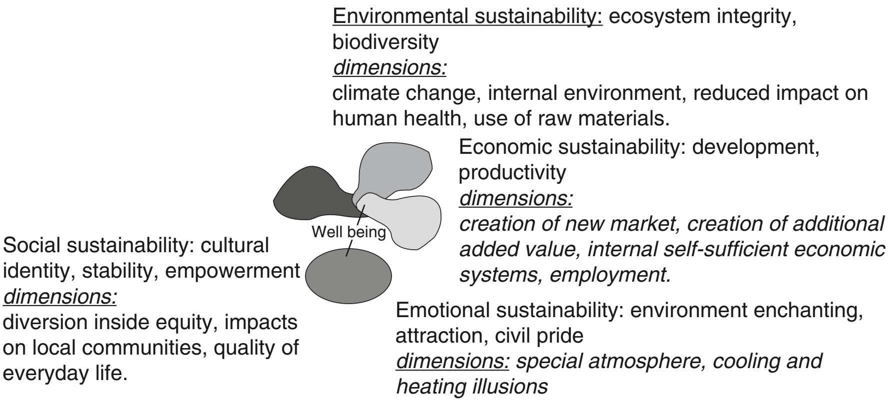
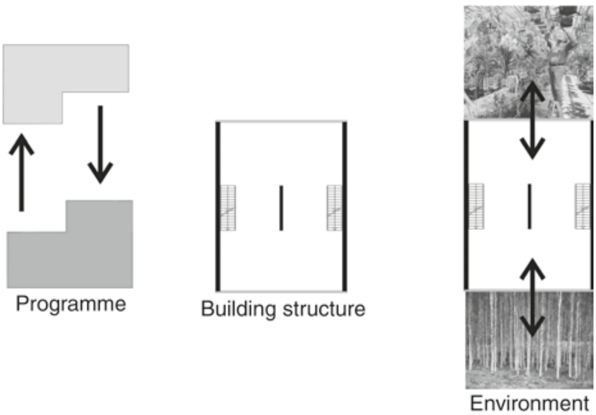


Fig. 8.3 Synergy of the three different parts of sustainability (social-economical-environmental) and introduction of the term “emotional sustainability”

Fig. 8.4 Horizontally repeated housing type with basic characteristics: every level is transversal; programmatic mixture (living-working); two facades on both sides, one facing the agricultural land and the other the “forest”. The other two sides are shared walls with neighbours



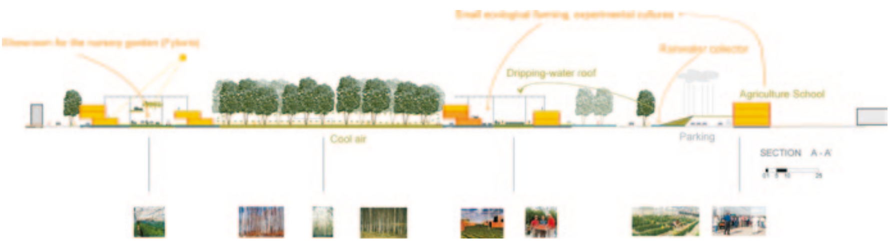


Fig. 8.5 Row housing as a border-wall to the agricultural area

these efforts. Now Germany has more than 100 intercultural gardens and the idea is adapted by other European countries.

Such gardens are considered a good typology for immigrants, though most of their knowledge is based in small farming and is not applicable in the German farming industry. These gardens provide a small plot for each user as well as a communal area, usually with trees, for shared gardening and happenings. The intention, except from putting down roots and gradually urbanizing (from field to garden), is to ex-

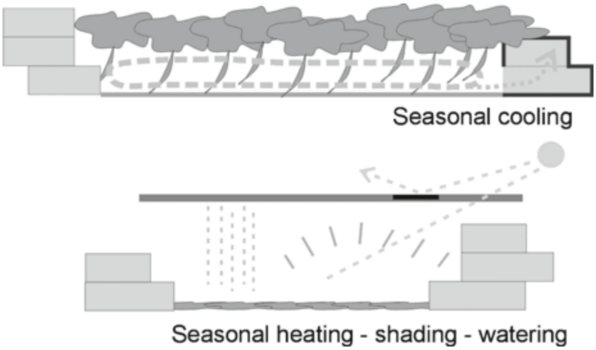


Fig. 8.6 Diagrammatic sections of the forest area and the greenhouse area. Cool air circulation, passive cooling and less thermal loss for the housing/border of the cultivations

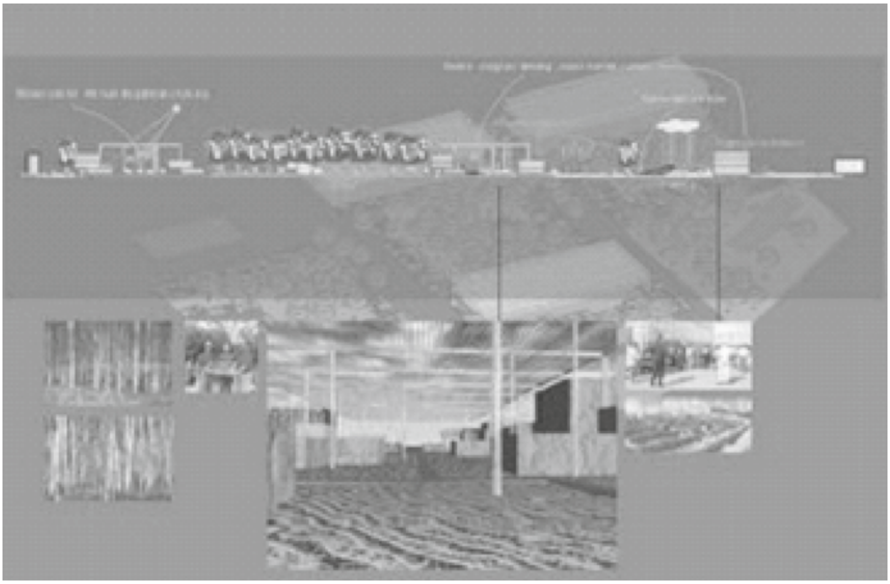


Fig. 8.7 Diagrammatic section of the whole area that demonstrates the relative autonomy of the managing system (biocultures, agriculture school, nursery garden, hill/rainwater collector, dripping water system, restaurants, less transportation of goods)

change tips for gardening based on their background. The results include exchanging seeds sent to them from their home country, to exchange tastes and flavours and offer new varieties, and to teach new techniques to their new country.

8.3 What is Transculturality

Since Herder's concept of "single cultures" (Spencer 1996), that sees culture as "the flower" of a folk's existence, like a sphere, autonomous and perfect in its own, societies have moved to today's multiculturality. Or, perhaps they had always been there. According to Wittgenstein (Welsch 1999), culture is at hand wherever practices in life are shared.

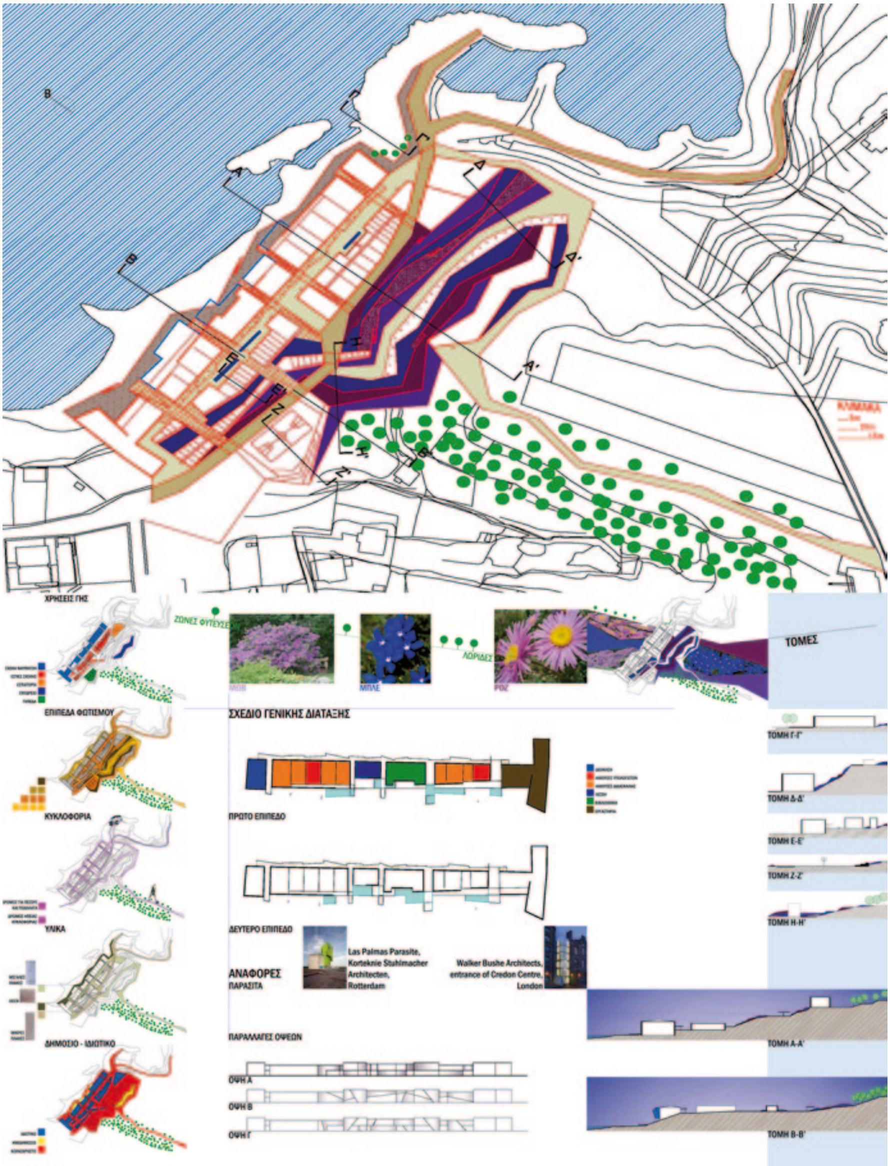


Fig. 8.8 Linear cultures in the in-between space of the old leather industries, the city fabric and the olive trees fields (peri-urban agriculture) together with a proposal for a cultural park, 2008. Students: Voradaki G., Tomara A., Chalkiadaki M. Urban design and policy for the old leather industries area, Chania, Crete, Greece. Main course of urban design II, 2007–2008. Tutors: Karamanea P., Karanastasi E

The difference in terms between intercultural and transcultural is that interculturality disagrees with the fact that different cultures clash, though transculturality argues that the clash is productive. Interculturality tends to make different cultures "get on" with each other and understand each other. But, it still originates from the concept of the single culture as a sphere, a perfect, accomplished product of society. In this way, one culture needs another only to enrich itself or for fun. Transculturality represents the complexity of the modern world, though it interprets cultures as a set of emergent components of one another.

The notion of culture today is more than an exchange—it is an interconnected system of ethics, an interactive platform of lifestyle norms, a hybrid field of mind-style fashions.

According to Welsch (1999), transculturality is originally defined on a macro-level: Cultures today are hybrids. In every culture, all other "outside" cultures possibly have penetrated or have influence as "satellites". Also, on second thought, transculturality is definable on a micro-level: We, ourselves, are cultural hybrids. Some mention in their biographical notes all the cultural influences as a basic component of their personality (e.g. authors today are not characterized by their land of origin but by their cultural structure, which is usually transcultural).

Nevertheless, the difference between cultural and national identity is important: Before the introduction of the term "transculturality", Berger et al. (1973) had referred to migration through different cultural worlds and to the successive realization of a number of possible identities. According to Berry and Epstein (1999), transculturality forms new identities in the "interference area" of different individuals and provokes the limits of discretion that are characteristics for nations and professions.

8.4 Transcultural Gardens: A Proposal for Intensification of Productive Urban Land Through the Combination of Various Minorities in Dialectic Relation

What is the difference between transcultural and intercultural gardens? What makes the proposed gardens different from those of Germany? The difference, as much as urban design is concerned, is in the programme and where they are to be located. Germany's intercultural gardens are mono-functional: They are gardens. And most of them are located in the countryside or suburbs. Transcultural gardens, as a proposal of this paper, research and demonstrate the dynamics of a complex and elaborated programmatic urban mixture (housing, social house, public programmes, leisure, commerce, flea market). They also try to prove the dynamics hidden in urban voids of dense city fabrics. Architectural and urban design has an important role: It confronts people and their needs, without entrenched identities and cultural divisions.

In modern thinking, transculturality applies in the fields of sociology and anthropology. The following four projects presented here, translate transculturality and urban agriculture into a device for urban planning. They are selected students' projects undertaken at the Technical University of Crete for addressing a big urban void of the city of Chania (Figs. 8.9–8.12).

8.4.1 Possibilities of Creation of Transcultural Gardens in Dynamic Urban Voids—The Example of the Old Military Camps in Greek Cities

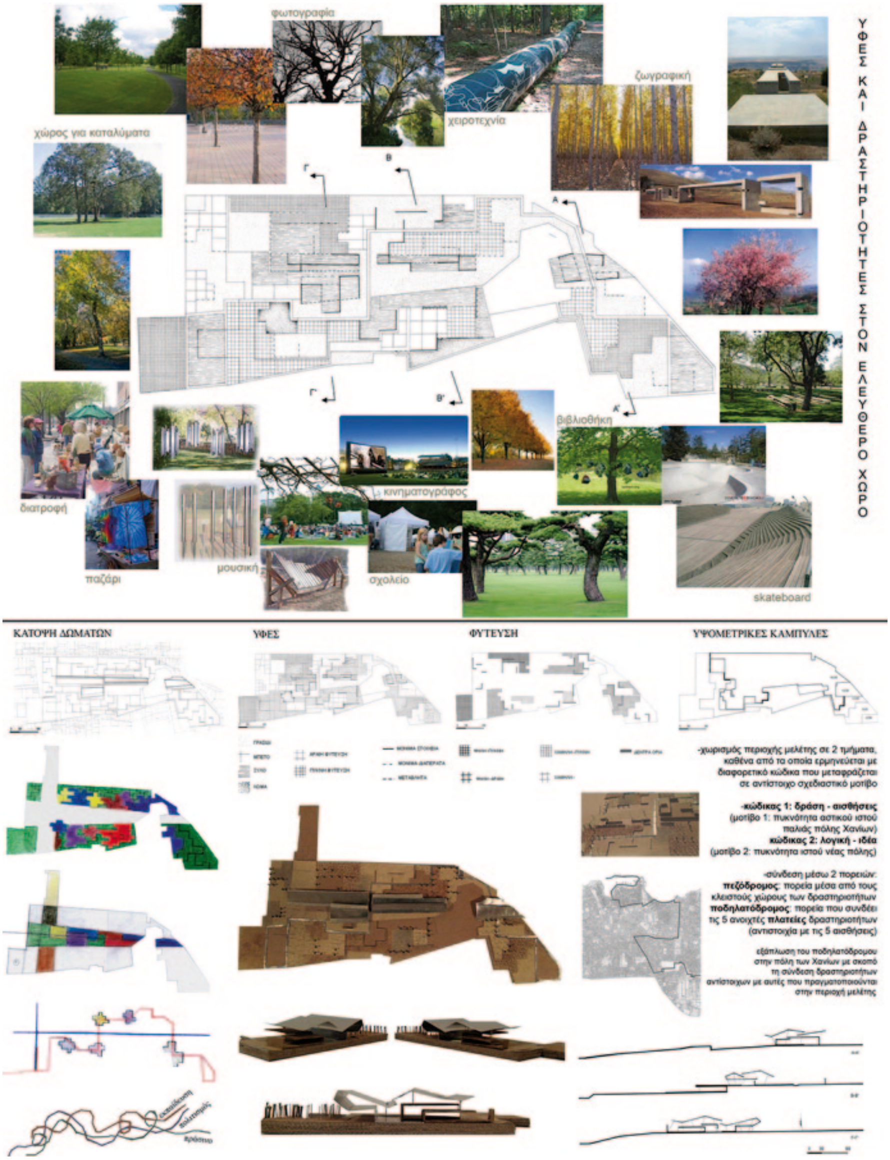


Fig. 8.9 Multicultural park, 2008. A combination of productive green, aesthetic green and public recreation areas with multicultural centre. Students: Alexopoulou E., Papatriantafyllou X., Terezaki A. Urban design and policy for the military camp of Markopoulos, Chania, Crete, Greece. Main course of urban design I, 2007–2008. Tutor: Elina Karanastasi. Collaborator: P. Karamanea

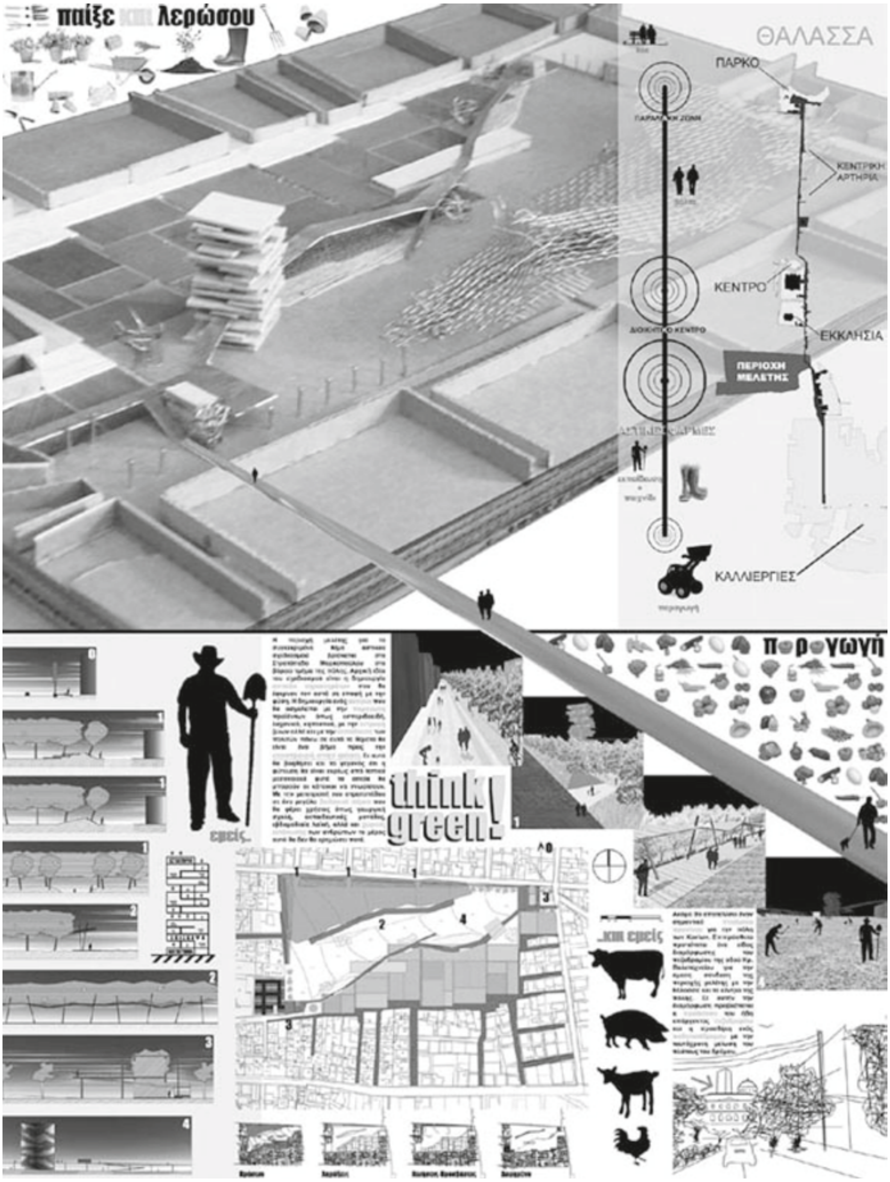


Fig. 8.10 Urban farms, 2008. Vertical farm, horizontal communal farm, flea market and park. Students: Athanailidi P., Maistralis E., Frizi Z. Urban design and policy for the military camp of Markopoulos, Chania, Crete, Greece. Main course of urban design I, 2007–2008. Tutor: Elina Karanastasi. Collaborator: P. Karamanea

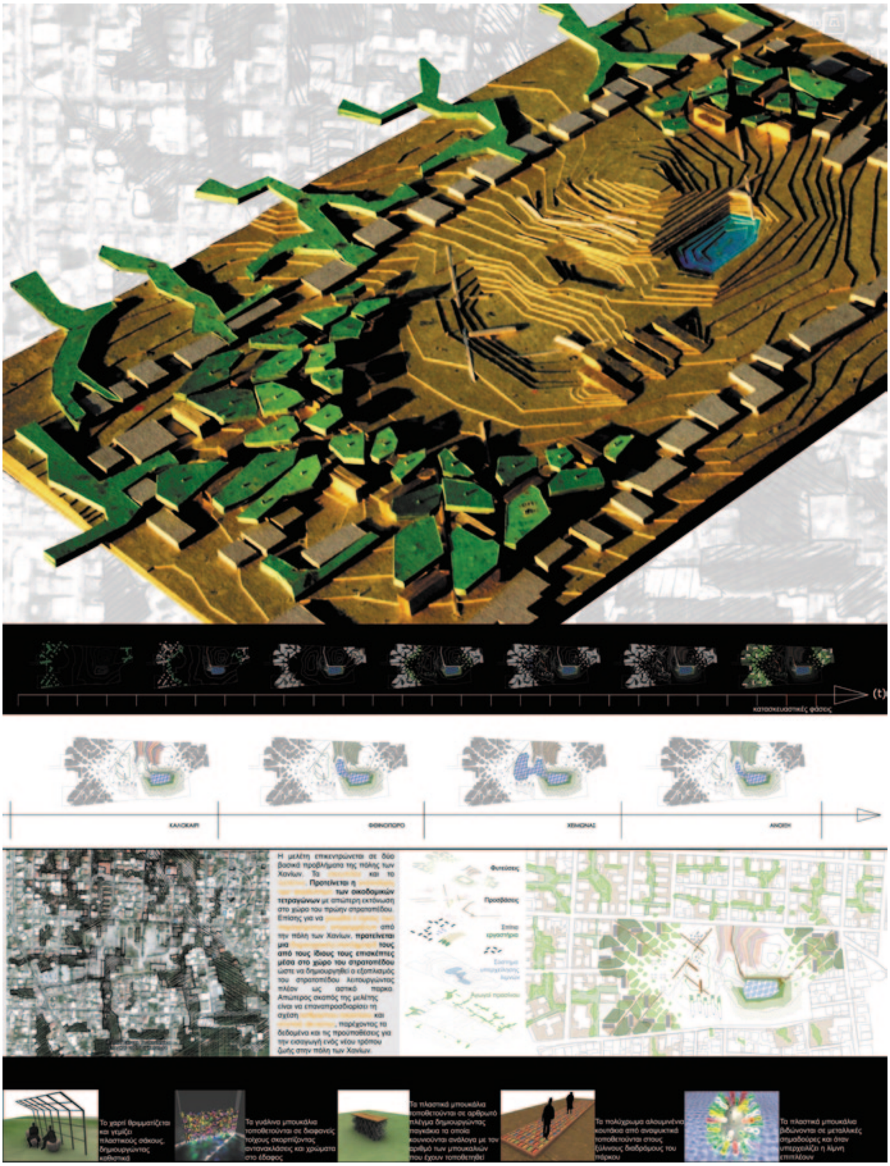


Fig. 8.11 Periodical altering park with urban cultures and recycling infrastructure that expands and unites the left-over open-air spaces of the surrounding area, 2008. Students: Asimakis N., Vlahiotis S. Urban design and policy for the military camp of Markopoulos, Chania, Crete, Greece. Main course of urban design I, 2007–2008. Tutor: Elina Karanastasi. Collaborator: P. Karamanea

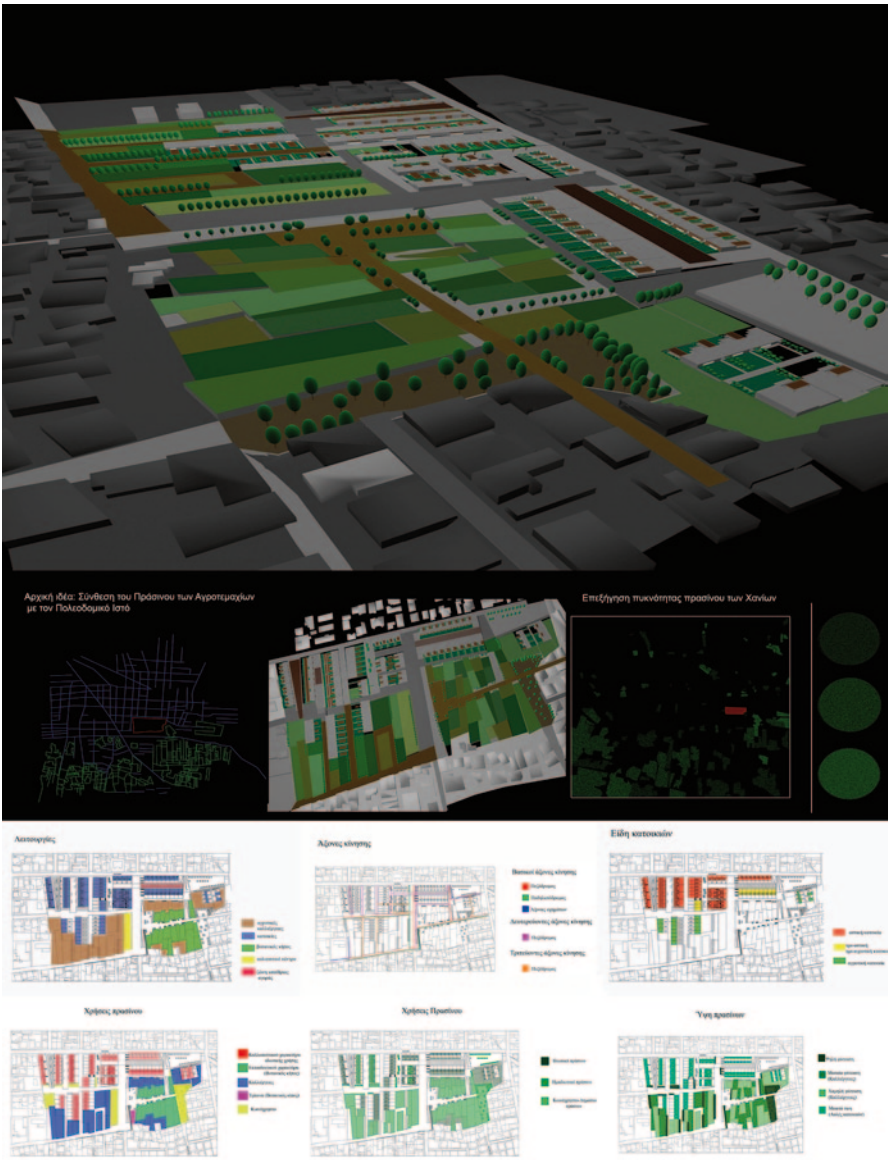


Fig. 8.12 From urban villa to urban cottage, 2008. Various layers of private and communal productive green areas. Students: Gregoriadou E., Relias G., Hassiotis N. Urban design and policy for the military camp of Markopoulos, Chania, Crete, Greece. Main course of urban design I, 2007–2008. Tutor: Elina Karanastasi. Collaborator: P. Karamanea

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Welsch W (1999) Transculturality—the puzzling form of cultures today. In: Featherstone M, Lash S (eds) Spaces of culture: city, nation, world. Sage, London, pp 194–213

Web Resources

Centre for Transcultural Studies. http://www.sas.upenn.edu/transcult/

Urban Agriculture News. http://www.urbanagriculture-news.com/

Resource Centre on Urban Agriculture and Food Security (RUAF). http://www.ruaf.org

Part II
Sustainable Management of Water Resources as a Prerequisite for Sustainable Agriculture Development

Chapter 9
Sustainable Rural Development and Participatory Approach by On-Farm Water Management Techniques

Ijaz Rasool Noorka

Abstract Food security is a human right and represents a serious threat to humankind, originating as it does from a worsening shortage of irrigation water. The sustainability of rural development is purely subjected to ethnic, gender and racial discrimination. The present study takes a look at the On-Farm Water Management (OFWM) programme, a participatory approach providing technical know-how and capital shares for watercourse construction, and improving the capacity building and empowerment of farmers to help them combat poverty and become socially mobile. Mapping, designing and watercourse improvement are contributed by the government, while farmers are obligated to pay their share in the form of labour. Local farmers have the necessary know-how about the field geographical area, raw material, procurement and local customs. During the course of this study, four Tehsils of the district of Faisalabad, Pakistan, were chosen as experimental units. The project conclusion resulted in 33% more water being saved by improved watercourses. About 25% arid area was brought under cultivation by saving irrigation water as well as generating 30% more employment. Overall, 50% of the economic situation was improved in rural areas, which is really a great step forward in achieving sustained rural development.

Keywords Capacity Building • Food Security • Sustainability • Participatory • Social Mobilization

9.1 Introduction

Pakistan is predominantly an agricultural country. However, current efforts are a far cry from the realization of optimum yield performance for almost all crops, mainly because their adaptation is limited and needs must be improved through efficient research before becoming accessible to farmers. Pakistan has a long latitudinal

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extension stretching from the Arabian Sea in the South to the Himalayan Mountains in the extreme North and has diversified physiographic features. This country is situated in an arid to semi-arid region, where average rainfall is on the low side, ranging between 254 and 356 mm against the essential demand of 1,778 mm (Khan 2003). The more-than-double gap between demand and supplies can be overcome by surface irrigation (Government of the Punjab, Irrigation & Power Department 2007).

The assured supply of irrigation water is a prime component of crop production and irrigation serves as a tool to increase the cropping intensity in this region (Dinger and Prasad 1987).

Globally speaking, there is a strong perception that in the future major wars between nations may take place just to access the water resources (PSF 1999). Water security is closely linked with food security, especially within developing countries. Pakistan's domestic and industrial water requirements are projected to rise by 15% in 2025 in contrast to the present consumption of 3% (PWP 1999).

Pakistan is under serious threat of rapidly increasing population with a growth rate of nearly 2.7% way back in 1948, when 32.4 million people were living in Pakistan, with a population likely to approach 208.06 million by the year 2025—a time bomb that may someday explode with nightmarish consequences (Pakistan Water Partnership 2007).

A burgeoning population pressure has created a water usage combination between arid and semi-arid zones of Pakistan. In Pakistan crop water requirements are 1,400 mm in Turbut (Balochistan), 900 mm in Parachinar (NWFP), 1,487 mm in Jacobabad (Sindh) and 1,280 mm in Faisalabad (Punjab). The per capita irrigation water has declined from 1,926 to 493 m^3 over the period from 1990 to 2025 (Seckler 1999).

In Pakistan, most farmers have unimproved watercourses and unlevelled fields, due to which irrigation water usage has been increased resulting in poor water application and overirrigation (Kahlown and Kemper 2004).

The excavation of the Lower Chenab Canal in 1892 and its aftermath—the availability of irrigation water from the mighty river Chenab—changed the whole appearance of the vast tract of land lying between the river Ravi and Chenab called Rachna Doab. In 1896 a town called Lyallpur arose from the plains of Punjab, named after Sir James B. Lyall, KCSI (Knight Commander of the Order of the Star of India), Lieutenant Governor of Punjab. The name of the city was changed to Faisalabad in 1977, in memory of the late King Faisal Bin Abdul Aziz of Saudi Arabia.

The Pakistani agriculture sector is facing a threat and challenge to produce more food with less water (Kijne et al. 2003). The major loss of available water occurs in rough water course systems in the country. The watercourses have poor design and lack regular cleaning and maintenance.

Due to developed irrigation systems a pilot On-Farm Water Management project was initiated in 1976–1977 with USAID assistance. The watercourse improvement program aims to reduce conveyance losses; it consists of alignment of community water courses, installation of precast naccas at all bifurcations for efficient diversions of water and to reduce the losses by up to 50%.

Lining of water courses is an effective technique to reduce seepage losses from watercourses and ensure sustainable rural development if participatory approaches can be implemented.

Keeping in view the importance of sustainable rural development and participation approaches initiated by On-Farm Water Management to improve watercourses and to calculate their efficiency, the present study was initiated in four Tehsils of the Faisalabad district to attract the attention of researchers and farmers so that sustainable rural development and participatory projects may be initiated in future.

9.2 Materials and Methods

9.2.1 Selection of the Study Area

Faisalabad district was selected as study area during the years 2006–2008. Its four Tehsils', namely Tandlianwala, Faisalabad, Jaranwala and Sammundri's, watercourses were selected for the reason that the farmers are not big land lords and their economic position is almost similar. Besides, the district is representative since all kinds of crops are grown there.

9.2.2 Inventory of Watercourses

Sr. No.	Area	Total watercourses	Improved	Unimproved
1	Tandlianwala	515	301	214
2	Faisalabad	964	890	74
3	Jaranwala	724	713	11
4	Sammundri	438	436	2
	Total	2,641	2,340	301

9.2.3 Canal Irrigation System of the Study Area

The Faisalabad district boundaries adjoin with the districts of Jhang, Chiniot, Toba Tek Singh, Hafizabad, Sheikhupura, Nankana Shahib, Okara and Kasuar.

9.2.4 Industry and Agriculture

Faisalabad is figuratively considered as the Manchester of Pakistan which owns multiple industries like textile mills, Refhan Maize Products, ghee mills, sugar mills, food products, soft drinks factories, flour mills, rice shelling mills, as well as University of Agriculture, Faisalabad, Ayub Agriculture Research Institute, Nuclear Institute for Agriculture and Biology (NIAB), National Institute Biological Genetic Engineering (NIBGE), Punjab Medical College, National Textile University, National Fertilizer Research Institute and Forest Research Institute Faisalabad.

9.2.5 Temperature

Weatherwise, extreme climate prevails in the study areas. The temperature approaches 52°C in summers and falls close to 0°C in winters.

9.2.6 Experimental Units

The experimental units were four watercourses of four Tehsils before and after improvement (Table 9.1).

9.2.7 Experimental Plot Size

The experimental plot size of 60 × 66 m remained constant in all experimental units. The plot was divided into sub-plots. The dimensions of each sub-plot were 15 × 66, 30 × 66, 45 × 66 and 60 × 66 m with a corresponding area of each measuring 990 m^2 (0.099 ha), 1,980 m^2 (0.198 ha), 2970 m^2 (0.297 ha), 3960 m^2 (0.396 ha), respectively.

9.2.8 Distance from the Outlet of the Canal

The experimental plot was selected at the distance of 300 m away from the outlet of the canal.

Table 9.1 Salient features of watercourses

Sr. no.	Water course no.	Tehsil	Distributaries	Chak no.	Command area (ha)	Sanctioned discharge (LPS)	Beneficiaries (no.)	Improvement cost (Rs)
1	33660/R	T/Wala	Balik	600 GB	582	50.00	65	14,48,425
2	16732/L	Faisalabad	Dijkot	289/RB	370	50.00	39	7,25,455
3	123780/TR	Jaranwala	Khurianwala	76/RB	506	50.00	44	5,04,370
4	10135/TCL	Sammundri	T/wala	414 GB	440	50.00	102	10,28,595

9.2.9 Area Profile

The plot area was levelled before the sowing of wheat crop. Immediately after harvesting the wheat crop, the experiment was conducted. The plot areas were irrigated while measuring flow and time consumed to fill the plots up to the depth of 6 cm standing water before improvement and after improvement of the watercourses.

9.2.10 Measurement of Time to Fill the Experimental Plots by Irrigation

The time needed to fill the experimental field was measured by using a stopwatch. The time required to obtain the desired depth of irrigation of each plot was noted down.

9.3 Results and Discussion

The findings of this study range over two phases. In phase 1, the results of reduction in time to irrigate the field are discussed while in phase 2, the effect of the participatory approach to improve the watercourses in sustainable rural development is discussed.

Phase 1: Results of Reduction in Time to Irrigate the Field In this phase, the experiment was conducted in a farmer's field using the participatory approach in an unimproved as well as an improved watercourse. The time consumed to apply the irrigation water in both is shown in Table 9.2. In the field plots measuring 0.099 ha the consumed time is 21 and 10.75 min respectively. the percentage of irrigation water saved in relation to unimproved and improved watercourses was calculated. According to the results, 33% of time was saved with improved watercourses. The same results have been reported by DGAWM (1998).

Table 9.2 Time applied and saved in unimproved and improved watercourses

Watercourse position	Plot size (ha)	Time consumed (min)	Time saved (min)	Time saved (%)	Cumulative percentage (%)
Unimproved	0.099	21.00	10.25	49	33
Improved	0.099	10.75			
Unimproved	0.198	28.50	8.75	31	
Improved	0.198	19.75			
Unimproved	0.297	30.75	3.75	13	
Improved	0.297	27.00			
Unimproved	0.396	65.25	25.50	39	
Improved	0.396	39.75			

Two-sample *t*-test and CI: T1, T2.
Two-sample T for T1 vs T2.

N	Mean	StDev	SE	Mean
T1	48	40.5	19.2	2.8
T2	48	25.5	12.0	1.7

Difference = mu (T1) − mu (T2).
Estimate for difference: 15.00.
95% upper bound for difference: 20.44.
T-test of difference = 0 (vs <): T-value = 4.59, *P*-value = 1.000, DF = 79.

Two sample *t*-tests were used to compare the difference in performance of different watercourses. Highly significant differences occurred between the time consumed to irrigate the specified number of plots. In the case of unimproved watercourse (T1) it took significantly more time to irrigate the specific number of plots compared with improved watercourse (T2). The average time for irrigation with T1 was 40.5 min with a standard deviation of 19.2 min, whereas the average time was only 25.5 min with T2 with a standard deviation of 12 min (Fig. 9.1). On average, the unimproved watercourse takes almost 20 min more compared with the other treatment (improved watercourse).

Phase 2: The Need for Farmers' Participation Watercourse improvement was found to increase water supply and decrease losses at farm level. Three types of watercourse improvement were considered very effective including "Pacca" lining (Hard surface lining), earthen improvement and after-care services. A critical review of the Pakistan water budget reveals that 49 MAF (million acre feet) of water are lost in tertiary level (watercourses and field application processes) of which the main causes were loss of water in watercourses through seepage, spillage and side leakage, which may be attributed to unmanaged watercourses or lack of farmer training and interest.

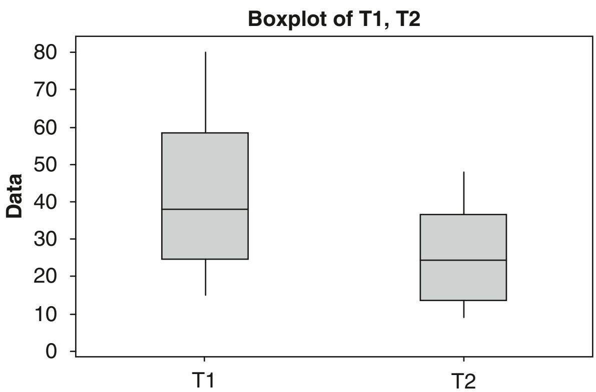

Fig. 9.1 Box plot of the two different types of water courses

The need for farmers' participation is a worldwide mentioned and accepted phenomenon. However, quite often some of the prerequisites for success are not realized. Several such prerequisites have been identified and are very relevant to changing the conventional implementing processes involved in the execution of On-Farm Water Management techniques, to be used in both rain-fed and irrigated conditions. These prerequisites include firm government commitment and sustained support to rural people for the establishment of new institutional arrangements. These commitments need to be expressed through rules and regulations to be developed by the farmer groups themselves, and strictly enforced for maximum benefit (Kijne 2001).

The government of Pakistan started the On-Farm Water Management program in 1977–1978 on a participatory basis with capital shares provided by the government (World Bank, Asian Development Bank, etc.) while the labour costs had to be borne by the farmers. They actively organise the work of demolishing the old and existing watercourses. The input offered by local people is critical in helping the technical person to do a profile survey of the area and to construct a contour plan and proper design of watercourse improvement. It was concluded that increase in irrigation increased the cropping intensity (apparent and real water productivity, AWP and RWP, as defined by Kassam and Smith 2001; findings of Jalota et al. 2006). It was noted that 33% more water was saved by improved watercourses, so that 25% of the arid area was brought under cultivation by saving irrigation water and it was possible to generate 30% more employment to sustain rural development by pooling all these efforts. It is feasible that the economic situation in rural areas can be improved by more than 50% and sustained rural development ensured. The current world food and energy crisis, the human and environmental impacts of globalization and climate change call for rethinking of agricultural and rural development in an integrated manner.

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Chapter 10
Sustainable Water Management for Irrigated Rice Production

Kruamas Smakgahn

Abstract Water is necessary to offset the water requirement of rice crops, especially under irrigated rice conditions (lowland, deepwater rice). Insufficient water supply during rice cultivation may obstruct the rice-growing rate and ultimate yield. On the other hand, anaerobic rice systems emit methane (CH_4), a greenhouse gas, and hence contribute to global warming. In this regards, introduction of aerobic rice systems may be an option to reduce CH_4 emissions and maintain water resources in the ecosystem. In an effort to reduce CH_4 emissions, the DNDC-rice model was used to validate CH_4 emissions under field conditions with various water management regimes including continuously flooded, mid season drainage, multiple drainage, and local farmer practice in the irrigated rice cultivation areas in Thailand. The results have shown lower CH_4 emissions from drainage fields than continuously flooded management. Relatively, longer field drainage presented a high potential for CH_4 reduction. Rice yields under four water managements were not significantly different; however, rice growth rate and water requirement was dissimilar. The water consumption under mid season drainage treatment was reduced by 5.3% and rice grain yield was increased by 5% compared to conventional water management at the study site. The results from model simulation can explain the phenomenon of electron donors/electron acceptors in rice soil. The contents of electron acceptors strongly affect CH_4 emissions from rice fields, particularly under alternative forms of water managements. The results from the field experiment and modeling suggested field drainage during growing season as one option to mitigate CH_4 emissions but maintain rice grain yield.

Keywords Methane • Model • Rice Production • Water Management • Yield

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10.1 Introduction

Water is necessary for rice cultivation, especially for irrigated rice (lowland, deep-water rice). In irrigated rice fields the floodwater is controlled and usually maintained throughout the growing season, these conditions are favorable for rice production. However, anaerobic conditions do occur in wetland rice fields which induce anaerobic conditions conducive for the growth of methanogenic bacteria and thus increase CH_4 emissions. It is well established that CH_4 production is a microbiological process by strict anaerobic bacteria (methanogens), which use compounds from the decay of organic matter as their food source and produce CH_4 as a by-product. The major pathways of CH_4 production in flooded rice soil are the reduction of carbon dioxide (CO_2) with hydrogen, with fatty acids or alcohol as the hydrogen donor, and the transmethylation of ethanoic acid or methanol by CH_4 producing bacteria (IPCC 1995).

Once conditions for CH_4 formation are ideal, the CH_4 formed is emitted to the atmosphere from wetlands via three primary modes: (1) diffusion of dissolved CH_4 across the water-interface; (2) bubble ebullition, and; (3) air circulation between the atmosphere and the buried tissues of aquatic plants, with the stems and leaves serving as conduits (Rogers and Whitman 1991). The diffusive flux through soil and floodwater is dependent on the concentration gradient. Enhanced CH_4 production in the rice paddy mainly results in more CH_4 transported by ebullition or plant-mediated transport and the relative contribution of diffusion through soil and floodwater decreases even further. More than 90% of the total CH_4 emissions over a season were due to plant-mediated transport, ebullition accounting for less than 10% (Denier van der Gon 1996).

Methane emissions from rice fields appear to be reduced by field drainage and some important cultivation practices. In general field drainage has been performed in order to protect the rice root from injury caused by extreme reduction conditions due to the decomposition of organic matter and substances toxic to rice plants (organic acid, Fe^{2+}). Increased water percolation and/or well times and short drainage periods during the growing season were found to reduce CH_4 emissions and do not necessarily reduce the rice yield (Sass et al. 1992, 1994).

In order to describe the phenomenon of flooded and drainage rice soil, the process-based model was helpful and the DNDC-rice model is appropriate. Recently the DNDC-rice model has been used to validate CH_4 emissions against field observations in the irrigated areas in Thailand, including Bangkok, Chainat, Khon Kaen, Pathumthani, Phitsanulok, Phrae, Chaingmai, Suphanburi, and Surin provinces. This model presented reasonable results with some uncertainties such as electron donors and acceptors in rice soil, the straw incorporation, and rice root biomass (Smakgahn et al. 2009). This presentation applied the DNDC-rice model for validation against observation under various water managements to determine sustainable water management for rice cultivation.

10.2 Materials and Methodology

10.2.1 The Model Description

The DNDC-rice model (Fumoto et al. 2008), the DNDC model (Li 2000) has been modified based on Japanese rice production focused on the crop growth sub-model. The crop growth sub-model was revised by incorporating an established model of crop carbon metabolism to explicitly describe photosynthesis, respiration, and C allocation with additional effects of N availability and atmospheric CO_2 concentration on photosynthesis. The crop carbon balance included carbon flux from root activity or root respiration to soil turnover and root exudation. Hence, CH_4 production is directly associated with the plant C metabolism. The CH_4 emission to the atmosphere was a function of the number of tillers and O_2 release from the rice root through CH_4 oxidation. The objective of revision was to quantify production and consumption of electron donors (H_2 and DOC) as substrates for CH_4 production and other reductive reactions. Only DOC was playing an important role as substrate for CH_4 production of the current DNDC model. The DNDC-rice model calculates production of electron donors due to anaerobic decomposition and root exudation, and the rates of reductive reactions are calculated by kinetic equations depending on the availabilities of electron donors and acceptors. The CH_4 emission rate is the function of conductance and density of rice tillers.

10.2.2 Study Sites

The DNDC-rice model was validated for CH_4 against field observations data at the Samutsakorn rice field in the central plain of Thailand (100° 200′ E, 13° 200′ N, Fig. 10.1). This area is located in one of the irrigated areas and this site had been cropped continuously for the last 20 years. Four different field drainage regimes were studied: the farmer method (FM), continuous flooding (CF), mid season drainage (MS), and multiple drainage (MTD). Farmer management practices in this area consist of flooding with flexible short drainage during a growing period. Mid-season drainage was conducted 64 days after planting (flowering stage) for a period of 6 days. Multiple drainage consisted of two intermittent drainage periods of three days duration conducted 21 days and 64 days after the initial flooding. The final drainage was applied for all treatments 15 days before harvesting. The ammonium phosphate (AP) fertilizer was applied 20 days after planting (DAP) as basal fertilizer (25 kg N ha^{-1}). Nitrogen as urea fertilizer was applied as top dressing fertilizer 29 days after planting. The AP fertilizer was applied again 47 days after planting as top-dressing fertilizer. The photoperiod insensitive non-jasmine rice cultivar Sp1 was used. Wet seeding with 187.5 kg of rice ha^{-1} was applied on August 12, 2002. The fields were flooded 7 days after planting and the water level

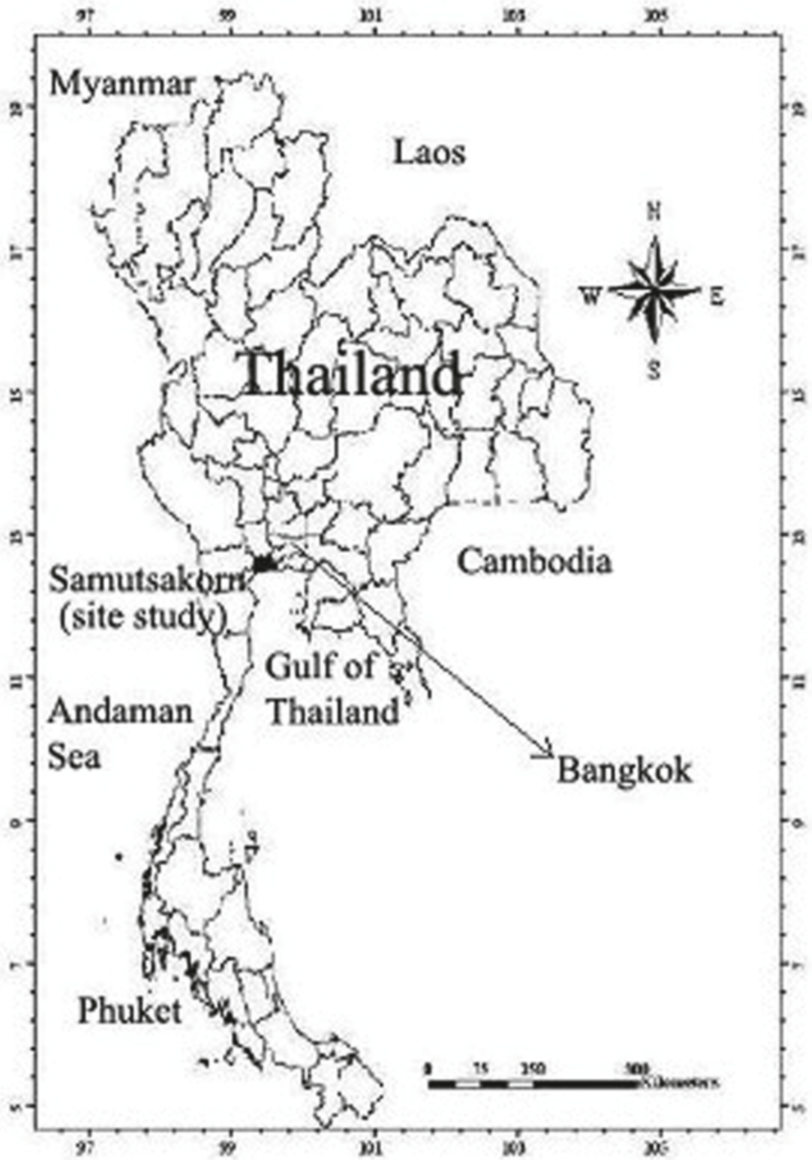

Fig. 10.1 Location of the site study

in each field was controlled (5–10 cm), except during drainage periods. Rice soil in this field experiment was Bangkok (Bk) soil series and the soil was classified as Typic Tropaquepts. This soil contained 1.31% of organic carbon and 0.06% nitrogen content under an initial soil pH of 6.10. Soil texture was clay with a percent-

Table 10.1 Physical and chemical characteristics of soil at site study (Towprayoon et al. 2005)

Soil property	
Soil pH	6.1
SOC at surface (%)	1.31
Phosphorus (ppm)	0.07
Nitrogen (%)	0.06
C:N ratio	20
Sand (%)	22
Silt (%)	24
Clay (%)	54
Soil texture	Clay
Initial soil moisture (water filled porosity)	0.53
CEC (meq/100 g soil)	No data

age composition of sand:silt:clay of 22:24:54 (Table 10.1). See Smakgahn (2003) and Towprayoon et al. (2005) for details of field experiment at Samutsakorn rice field.

10.3 Results and Discussions

The site mode of the DNDC-rice model was validated against field observation data in the Samutsakorn experiment. The model presented only ~3% lower seasonal emissions than the observation under MS, ~4% and ~6% higher than observations under CF and LM treatment, respectively. However, large discrepancy from the model simulation was found under MTD, which was ~40% above the estimated value (Fig. 10.2).

The highest CH_4 flux has been observed at the reproductive period (80 DAP) due to suitable environmental conditions for methanogenesis activity (Towprayoon

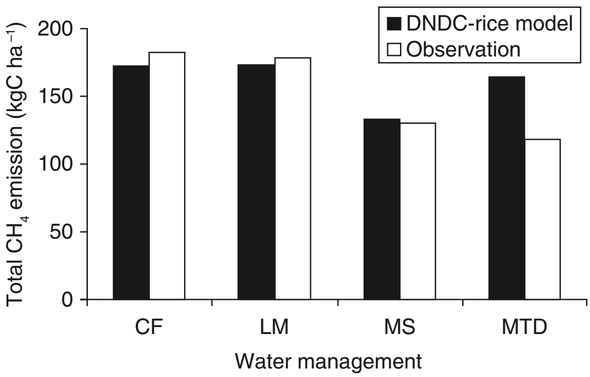

Fig. 10.2 Total seasonal methane emissions from field observation and model validation at study site. Where *CF* is continuously flooded, *LM* is local method, *MS* is mid season drainage, and *MTD* is multiple drainage

et al. 2000). These conditions included soil pH, strong anaerobic conditions in flooded soil, and abundant exudates secretion from roots into the rhizosphere (Pusatjapong et al. 2003). Submerging soils increases the availability of P, K, Ca, Si, Fe, and Mn, and this could be beneficial to irrigated lowland rice (Yoshida 1981). However, the CH_4 emissions from MTD and MS treatment, where water drainage commenced shortly before the reproductive period, were less compared to the other treatments.

The contents of electron acceptors will strongly affect CH_4 emissions from rice fields, particularly under alternative forms of water managements (Fumoto et al. 2008). The concentration of Fe^{+2} under drainage treatments (LM, MS, and MTD) was higher than under CF. The Fe^{+2} in flooded rice soil was oxidized during the drainage period and functioned again as electron acceptor and inhibited CH_4 production in subsequent flooded periods (Fumoto et al. 2008). However, the discrepancy was presented under MTD; higher concentration of DOC may be a cause of higher emissions compared to CF in the model simulation (Fig. 10.3a, b).

Model simulation of rice grain yield under CF, LM, MS, and MTD are shown in Fig. 10.3. Rice grain yield under mid season drainage was ~5% higher than under CF treatment. Under MTD, grain yield was ~0.4% higher than under CF treatment and ~6% less than under MS treatment. The amount of rice shoots and roots from various water managements simulated by the model presented similar results as

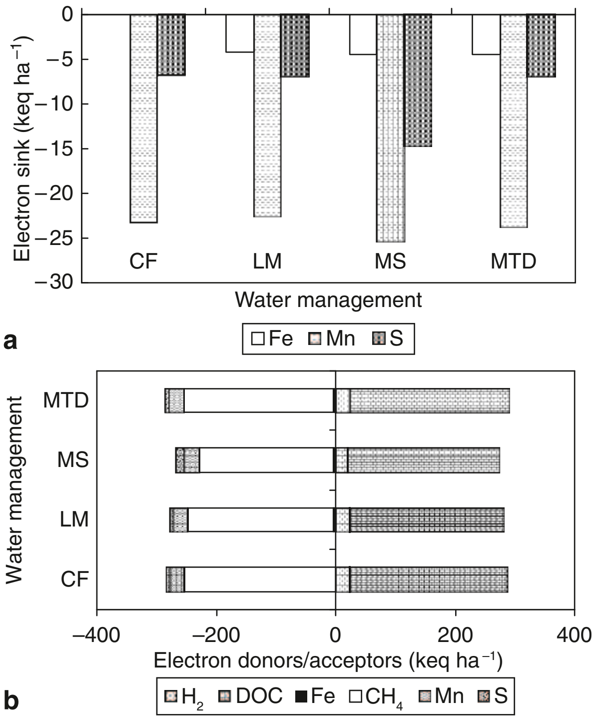

Fig. 10.3 Electron budget under different water management regimes; **a** electron sink and **b** electron donors/acceptors. Where *CF* is continuously flooded, *LM* is local method, *MS* is mid season drainage, and *MTD* is multiple drainage

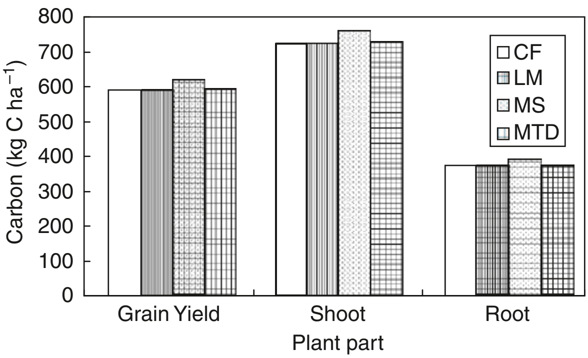

Fig. 10.4 Rice grain yield, shoot, and root carbon under various water management regimes. Where *CF* is continuously flooded, *LM* is local method, *MS* is mid season drainage, and *MTD* is multiple drainage

with the rice grain yield (Fig. 10.4). The longer drainage period of MS reduced the extreme reduction condition due to the decomposition of organic matter and substances (organic acid, Fe^{2+}) toxic to rice plants. In addition, the aerated condition provided oxygen to rice roots which is useful for rice growth. But the short drainage period of MTD was not long enough for air ventilation in wet rice soil. These results comply with previous research that increased water percolation and/or well times and short drainage periods during the growing season were found to reduce CH_4 emissions and do not necessarily reduce the rice yield (Sass et al. 1992, 1994).

Rice fields in irrigated areas are fully water controlled by irrigated system. Paddy rice needs much more water: the suitable water consumption average is 843–1,125 mm per one crop (1,350–1,800 m^3 of water per crop) (Polsan et al. 2004). The simulated results of water consumption under various water managements are shown in Fig. 10.5. Water consumption for rice cultivation under drainage conditions (MTD, MS, and LM) was lower than under the CF treatment about by 4.5–5.3%. Mid season drainage required the lowest water supply compared to other treatments.

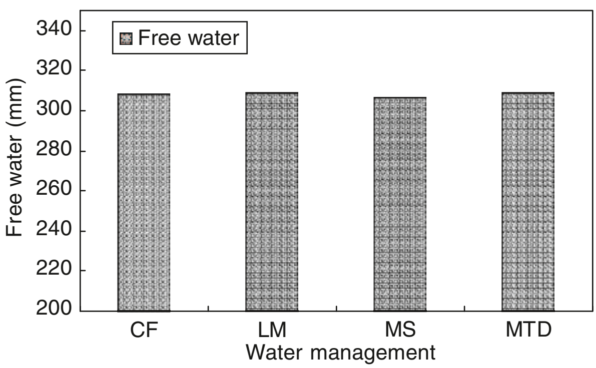

Fig. 10.5 Free water consumptions for rice cultivation under various water management regimes. Where *CF* is continuously flooded, *LM* is local method, *MS* is mid season drainage, and *MTD* is multiple drainage

10.4 Conclusion

The results from the field experiment and modeling suggest that field drainage conducted during growing season is one option to mitigate CH_4 emissions but maintain rice grain yield. MS water management is an interesting candidate to reduce water consumption for the mid season and maintain rice grain yield. The water consumption was reduced by 5.3% and rice grain yield was increased by 5% compared to the conventional water management at the study site. The MS condition for rice cultivation might be beneficial in irrigated rice-growing areas for sustainable rice production. However, further economic study is required in order to obtain the practical management.

The DNDC-rice model simulation results can explain the phenomenon of electron donors/electron acceptors in rice soil. The contents of electron acceptors strongly affect CH_4 emissions from rice fields, particularly under alternative forms of water managements.

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Chapter 11
Reduction of Water Losses by Use of Alternative Irrigation Techniques in the Aral Sea Drainage Basin

Rebecka Törnqvist and Jerker Jarsjö

Abstract The Aral Sea drainage basin (ASDB) in Central Asia is a region under severe water stress. Its population depends to a large extent economically on irrigated agriculture, which consumes over 90% of the withdrawn freshwater in the drainage basin. There is thus a strong need to increase the water productivity, i.e. the ratio between crop production and water use. We analyse impacts on water use of possible large-scale implementations of alternative irrigation techniques, replacing traditional furrow irrigation on cotton fields in the ASDB. We base our quantifications on experimental field comparisons of yield and water use between traditional furrow irrigation and alternative irrigation techniques (drip irrigation, alternate furrow irrigation, surge flow irrigation and surge flow irrigation on alternate furrows). All alternative methods, except drip irrigation, are associated with lower cotton yields than the traditional furrow irrigation. In order to keep the cotton production unchanged when yields are lower, extended irrigation areas are needed, over which non-negligible additional water volumes will be lost. We show that despite such negative feedback effects, the irrigation water use on cotton fields in the ASDB could decrease by as much as 10 km^3/year, if the traditional furrow irrigation were to be replaced by one of the investigated alternative methods. Such decreases in water use can considerably influence the hydrological conditions in the entire basin. In particular, by reducing the severe water stress in the lower ASDB, which suffers from elevated groundwater tables, and high soil and groundwater salinity.

Keywords Aral Sea • Cotton • Hydrology • Irrigation • Water Productivity

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11.1 Introduction

The agricultural sector alone consumes about 70% of the earth's freshwater resources (World Resources Institute 2005). Agricultural water management has thus an immense impact on the hydrology in a river basin. Particularly in water scarce regions, there is a need to use irrigation water efficiently. The ratio between crop production and water use is called water use efficiency or water productivity and is often used to compare different irrigation systems in terms of water savings (Periera et al. 2002). Increased water productivity can be achieved by different means, for instance by changing the crop pattern to less water thirsty crops, increasing the yield by improving soil fertility or by applying less irrigation water to the fields by the use of more water efficient irrigation techniques (Molden et al. 2007).

The Aral Sea drainage basin (ASDB) in Central Asia is a region of physical water scarcity (Molden et al. 2007) and provides an example of the severe effect that overexploitation of water resources for irrigation purposes can have on an entire ecosystem. The agricultural production in the region, especially of cotton, underwent an enormous expansion during the Soviet period (Saiko and Zonn 2000). The required increase in river water diversions to the irrigated fields has had a great impact on the hydrology of the basin by decreasing the inflow to the Aral Sea by about 47 km^3/year, elevating groundwater tables and increasing soil and groundwater salinisation (Saiko and Zonn 2000). The agricultural sector consumes on average 92% of the freshwater resources in the ASDB. About one quarter of the region's Gross Domestic Product (GDP) is generated within agriculture and about one third of the population is working in this sector (World Resources Institute 2005).

Furrow irrigation, in which water is led through the fields in small channels, is the dominant irrigation method in Central Asia. Surge flow irrigation, alternate furrow irrigation and drip irrigation provide examples of alternative and potentially more water efficient techniques to traditional furrow irrigation. In surge flow irrigation, water is non-uniformly applied, which reduces deep zone percolation and runoff, and allows for a more uniform infiltration (Ismail 2006). In alternate furrow irrigation, one of two neighbouring furrows is alternately irrigated at each irrigation occasion. The water use is reduced due to more frequent irrigation of a small portion of land (Ünlü et al. 2007). Drip irrigation reduces the water use compared to surface irrigation by more frequent and more localised application of water by emitters to the root zone (Mateos et al. 1991). Regional modelling of how changes in irrigation practice affect crop production indicate that alternative irrigation techniques can be advantageous for the ASDB both economically and ecologically (see, e.g. Cai et al. 2003).

In the ASDB, experiments with alternative irrigation techniques have been performed by Ibragimov et al. (2007) and Horst et al. (2007), see Table 11.1 row 1 and 2 and Fig. 11.1. Ibragimov et al. (2007) carried out a three-year field study of drip irrigation and traditional furrow irrigation on a silty loam soil in the Tashkent

Table 11.1 Summary of the local conditions, systems investigated and results of the studies on alternative irrigation techniques for cotton production

Study	Year	Area	Climate	Soil texture	Alternative irrigation technique	Yields	Water use
Ibragimov et al. 2007	2003–2005	Tashkent region, Uzbekistan (41° 42′ N, 69° 49′ E)	Semi-arid, seasonal rainfall of 75–104 mm	Silt loam	Drip irrigation	10 to 19% increase	18 to 42% reduction
Horst et al. 2007	2003	Ferghana valley, Uzbekistan (40° 77′ N, 71° 09′ E)	Semi-arid, seasonal rainfall of 70 mm	Silt loam	Alternate furrows, continuous flow (AC)	13% reduction (AC)	29% reduction (AC)
					Surge flow on every furrow (ES)	12% reduction (ES)	21% reduction (ES)
					Surge flow on alternate furrows (AS)	13% reduction (AS)	44% reduction (AS)
Ünlü et al. 2007	1993–1995	Harran plain, southeast Turkey (36° 42′ N, 38° 58′ E)	Semi-arid, annual average rainfall of 365 mm	Clay	Surge flow irrigation (S)	15% reduction to 19% increase (S)	3 to 25% reduction (S)
					Variable alternate furrow irrigation (A)	11 to 22% reduction (A)	43 to 49% reduction (A)
Kanber et al. 2001	1991–1992	Harran plain, southeast Turkey (36° 42′ N, 38° 58′ E)	Semi-arid, annual average rainfall of 365 mm	Clay	Surge flow	–	2 to 22% reduction
Ismail 2006	2004	Assiut, Egypt (27° 11′ N, 31° 10′ E)	Arid, annual average rainfall of 2 mm	Clay	Surge flow (different tillage systems compared)	–	10 to 11% reduction
Ismail et al. 2004	–	Assiut, Egypt (27° 11′ N, 31° 10′ E)	Arid, annual average rainfall of 2 mm	Clay Sand	Surge flow	–	13 to 36% reduction (clay) 22 to 27% reduction (sand)

Table 11.1 (continued)

Study	Year	Area	Climate	Soil texture	Alternative irrigation technique	Yields	Water use
Cetin and Bilgel 2002	1991–1994	Harran plain, southeast Turkey (36° 42′ N, 38° 58′ E)	Semi-arid, annual average rainfall of 390 mm	Clay	Drip irrigation	21% increase (averaged max values)	–
Rajak et al. 2006	2000–2002	Gangavathi, Karnataka, India (15° 15′ 40″ N, 76° 31′ 45″ E)	Semi-arid, seasonal rainfall of 468 and 484 mm	Clay	Drip irrigation (varying soil salinity and applied irrigation water compared)	5 to 217% increase, 9 to 42% increase in moderately saline soils	9 to 22% reduction
Mateos et al. 1991	1985–1986	Cordoba, Spain (37° 53′ N, 4° 46′ W)	Mediterranean climate, seasonal rainfall of 48 and 80 mm	Sandy loam soil	Drip irrigation	10% decrease to a 23% increase	–

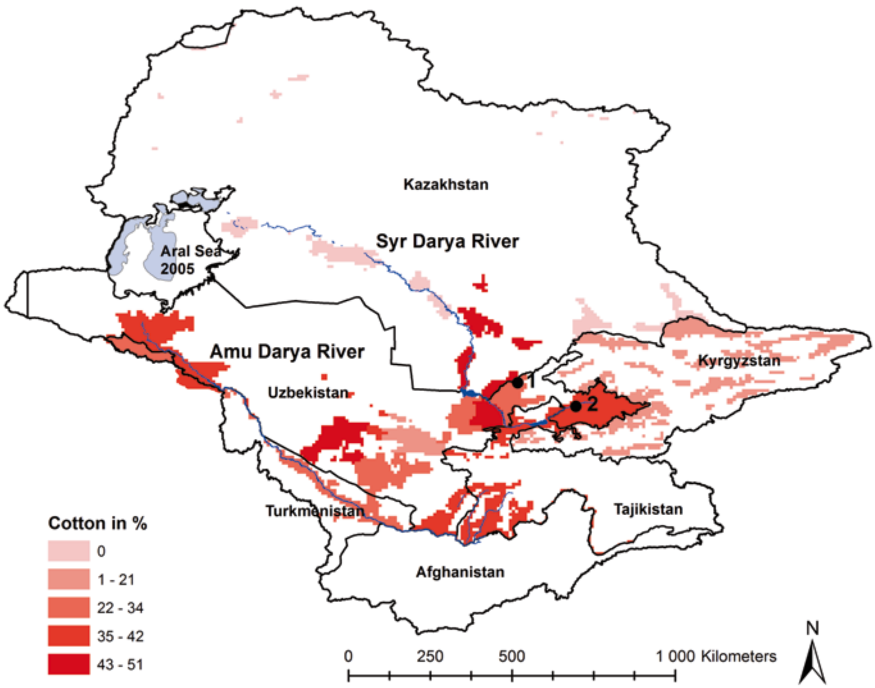

Fig. 11.1 The cotton distribution in the Aral Sea drainage basin as percentage of the total irrigated areas for different regions. The locations for the experimental field study sites in Ibragimov et al. (2007) and Horst et al. (2007) are marked with 1 and 2, respectively

region in Uzbekistan. A change from furrow irrigation to drip irrigation implied that water use was reduced by between 18 to 42%, while the yield increased by between 10 to 19%. Horst et al. (2007) performed a comparative study of continuous furrow irrigation on every furrow, i.e. traditional furrow irrigation (EC), surge flow irrigation on every furrow (ES), continuous flow on alternate furrows (AC) and surge flow on alternate furrows (AS). The irrigation experiments were carried out during one season on an experimental field of silty loam soil located in the central Ferghana Valley in Uzbekistan. The water use was reduced, in comparison with EC, by 21% for ES, 29% for AC and 44% for AS while the yield was reduced, in comparison with EC, by 12% for ES, 13% for AC and 13% for AS. The alternate methods were thus superior to irrigation on every furrow.

In this study we quantify how much water use can be reduced in the ASDB through use of alternative irrigation techniques at the cotton fields instead of traditional furrow irrigation, while keeping today's total; (1) cotton area and; (2) cotton yield. The quantifications are mainly based on measurement data, from, for instance, experimental fields in the ASDB.

11.2 Study Site

The ASDB lies within the borders of Uzbekistan, Tajikistan, Turkmenistan, Kyrgyzstan, Kazakhstan and Afghanistan (Fig. 11.1). The main part of the basin of 1,874,000 km^2 is situated in a semi-arid climate zone with cold winters and warm summers (Nezlin et al. 2004). The discharge into the Aral Sea from its two main tributary rivers has decreased by more than 90% due to agricultural water diversions, down to about 6 km^3/year in the northern Syr Darya river (Friedrich 2009) and less than 1 km^3/year in the southern Amu Darya river (Oberhänsli et al. 2009). Low flow in the Amu Darya does not only imply reduced inflow to the Aral Sea but also decreased freshwater availability in ecologically important wetlands, lakes and reservoirs in the Amu Darya delta.

Our study site comprises all irrigated regions in the ASDB except for relatively limited regions (allocating <3% of the irrigation water in the ASDB) situated in Afghanistan, outside of the former Soviet Central Asia. We use the same delineation of the ASDB as Shibuo et al. (2007). Uzbekistan is the biggest cotton producer in Central Asia and stands for about two thirds of the production in the region. The cotton production is mainly located in the southern part of the ASDB (Fig. 11.1). Cotton is the major crop in the South Kazakhstan region and in the Bukhara and Syrdaryio regions in Uzbekistan, where it constitutes about 50% of the total irrigated areas. In Kyrgyzstan, however, cotton only constitutes about 3% of the total irrigated areas.

11.3 Interpretation Methods and Irrigation Development Scenarios

We specifically consider reductions in water use related to improved irrigation techniques on cotton fields. Cotton production has a great impact on the irrigation water use in the ASDB due to its prevalence and high water requirements. Furthermore, we do not consider water use reductions related to changes in cropping patterns, since cotton is an important cash crop and important for the GDP of the countries. For Uzbekistan we used regional data on cotton production (derived from reported crop patterns; Bucknall et al. 2003) in the country's 13 administrative regions. For Kazakhstan, Kyrgyzstan, Tajikistan and Turkmenistan, data on national cotton production were used (United States Department of Agriculture 2009). All cotton production in Kazakhstan is located within the ASDB in the South Kazakhstan region (Bishimbayeva et al. 2008). The total cotton production within the ASDB-part of Kyrgyzstan, Tajikistan and Turkmenistan was estimated based on reported total national cotton production (United States Department of Agriculture 2009) times the proportion of the country's total area of irrigation that lies within the ASDB. For all countries, except for Kyrgyzstan, data on the area of cotton production were available for 2006/2007. Data of projected area harvested in 2008/2009 was used for Kyrgyzstan (United States Department of Agriculture 2009).

Table 11.2 Country specific data of irrigated areas, area of cotton production, water withdrawals for agricultural purposes and percentage of irrigated areas within the drainage basins of Amu Darya and Syr Darya, respectively

	Irrigated area [ha][a]	Area of cotton production [ha][b]	Water withdrawals for agriculture [km^3/year][c]	Area in AD [%][a]	Area in SD [%][a]
Kazakhstan	835,000	200,000	12.9	0	100
Kyrgyzstan	1,075,000	33,000	9.5	4	96
Tajikistan	719,000	260,000	11	67	33
Turkmenistan	701,000	240,000	9.7	100	0
Uzbekistan	4,223,000	1,430,000	54.3	55	45
Total	7,553,000	2,163,000	97.4	–	–

[a] Global map of irrigation areas, available at http://www.fao.org/nr/water/aquastat/irrigationmap/index.stm

[b] United States Department of Agriculture, available at http://www.fas.usda.gov/cotton_arc.asp

[c] World Resources Institute 2005, Table 9, p 208

The water use of today's traditional furrow irrigation on cotton fields in a country is calculated as the country's specific water withdrawals (Table 11.2; World Resources Institute 2005) times the percentage of the total irrigated areas used for cotton production in the country (Fig. 11.1) times the proportion of the irrigated areas of the country that lies within the ASDB. Today's total water use on cotton fields in the ASDB is calculated as the sum of the calculated cotton irrigation water use in the five ASDB countries. The water withdrawals for agriculture (Table 11.2) include water consumption for irrigation, delivery losses and return flows (World Resources Institute 2005). We assume that water losses in the distribution system will be reduced proportionally to decreases in the water application over the irrigated fields, according to a 1:1 relation. This assumption implies that the water distribution efficiency of the system as a whole will remain constant, despite changes in absolute flows.

We depart from field data from the ASDB on changes in water use and yield that result from changing the traditional furrow irrigation (used in practically all of the ASDB's irrigated fields) to an alternative irrigation method, such as drip irrigation (Ibragimov et al. 2007), surge flow, alternate furrow irrigation and alternate surge flow (Horst et al. 2007), see Table 11.1 row 1 and 2. For drip irrigation, we assumed 32% water use decrease and 14% yield increase, which is in the middle of the ranges from the study of Ibragimov et al. (2007), see Table 11.1 row 1. Throughout the analyses, we assume that all irrigated cotton fields within the ASDB are transformed to one of the alternative irrigation methods. Furthermore, we consider two irrigation development scenarios, namely: (1) a constant-area scenario, in which the area of irrigated fields is assumed to be the same before and after the change of irrigation methods, and; (2) a constant-production scenario, in which it is assumed that farmers will compensate any yield changes associated with the alternative irrigation methods, by increasing or decreasing their area of irrigation such that their total production remains the same. For instance, if an alternative technique provides higher yields per hectare than the traditional furrow irrigation, a smaller area is required in order to obtain the same cotton production. This assumption hence explicitly accounts for possible positive and negative feedbacks caused by yield differences between the traditional furrow irrigation and the alternative methods.

The effectiveness of a given irrigation method (in terms of water use and yield) can differ from location to location due to differences in, e.g. soil texture and local climate. The effectiveness may also differ from year to year due to changing weather conditions. We consider differences in reported effectiveness of each alternative irrigation technique, by analysis of an extended dataset (Ibragimov et al. 2007; Horst et al. 2007; Ünlü et al. 2007; Kanber et al. 2001; Ismail 2006; Ismail et al. 2004; Cetin and Bilgel 2002; Rajak et al. 2006; Mateos et al. 1991; Table 11.1) that also includes studies from different locations having climatic conditions similar to those found within the ASDB. In summary, all the studies reported reduced yields for alternate furrow and surge flow irrigation, compared to traditional furrow irrigation. The exception is Ünlü et al. (2007) who reports inconclusive yield trends for surge flow irrigation. For drip irrigation, all studies reported increased yield compared to traditional furrow irrigation, except for inconclusive results of Mateos et al. (1991). Mateos et al. (1991) is the only considered study of drip irrigation in sandy soil. Spatial differences in soil texture could thus potentially have significant impacts on drip irrigation yields. No significant difference was identified between water use for surge flow irrigation on clay soil and sandy soil in the study by Ismail et al. (2004); the reduction interval for the sandy soil was contained within the larger interval for the clay soil.

From our analysis of this extended dataset, we extract and report results in terms of ranges (e.g. possible maximum and minimum reductions in water use). The ranges for reductions in water use of the alternative methods compared to traditional furrow irrigation were 9 to 42% for drip irrigation, 2 to 36% for surge flow irrigation and 29 to 49% for alternate furrow irrigation. Yield changes varied between 10% decrease to 217% increase for drip irrigation, 15% decrease to 22% increase for surge flow irrigation and 11 to 22% decrease for alternate furrow irrigation. Ibragimov et al. (2007) report the largest reduction in water use for drip irrigation and Horst et al. (2007) report the smallest reduction in water use for alternate furrow irrigation. For surge flow on alternate furrows, such ranges could not be estimated, since the quantifications are based on data from one single field study. Regarding soil texture effects, we assume that the yield of the drip irrigation method will be lower when the soil has a sand content of at least 50%. For the maximum, average and minimum water reduction scenarios, we assumed a 23% yield increase, a 2% yield increase and 10% yield decrease, respectively, which is consistent with the range found experimentally by Mateos et al. (1991). The reductions were prescribed for regions with soils of at least 50% sand according to the ISRIC World Soil information raster data (Batjes 2005). For drip irrigation, the highest yield increase is reported for saline soils (Rajak et al. 2006). Minimum and maximum yield changes of moderately saline soils of 9% and 42% (Rajak et al. 2006), respectively, was applied in regions with a sand content smaller than 50%.

11.4 Results and Discussion

The black bars in Fig. 11.2 show that in the ASDB the current irrigation water use on cotton fields is about 30 km^3/year. The grey bars in Fig. 11.2 show estimations of how cotton irrigation water use would change if the traditional furrow irrigation were to be replaced by one of the alternative irrigation methods (drip irrigation, alternate furrow irrigation, surge flow and alternate surge flow irrigation). In the constant-area scenario for irrigation development (Fig. 11.2a), the alternate surge flow method is associated with the largest reductions in irrigation water use (of 13 km^3/year compared to traditional furrow irrigation), followed by drip irrigation (10 km^3/year), alternate furrow irrigation (9 km^3/year) and surge flow irrigation (6 km^3/year). These quantifications were made considering (average) water use data from experimental fields within the ASDB. The error bars in Fig. 11.2 show corresponding quantifications considering the extended dataset described in Sect. 11.3. For instance, the low-end value of the estimated range for the alternate furrow irrigation technique (Fig. 11.2a) shows that the water use can possibly decrease down to 15 km^3/year.

All the alternative irrigation methods can generate water use reductions in comparison with traditional furrow irrigation (Fig. 11.2a). However, all alternative methods applied at experimental fields of the ASDB are associated with lower yields than traditional furrow irrigation, except for drip irrigation (Table 11.1). The constant-area scenario for irrigation development (Fig. 11.2a) then implies that the total cotton production will be reduced when changing irrigation method. The constant-production scenario, considered in Fig. 11.2b, additionally accounts for

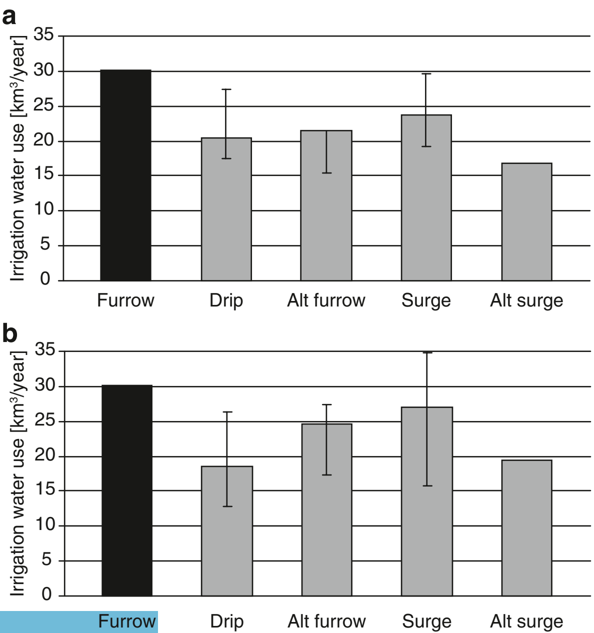

Fig. 11.2 Comparison of irrigation water use for cotton production in the Aral Sea drainage basin in km^3/year for: traditional furrow irrigation (*Furrow*; *black bars*), drip irrigation (*Drip*), alternate furrow irrigation (*Alt furrow*), surge flow irrigation (*Surge*) and alternate surge flow irrigation (*Alt surge*) under **a** constant irrigation area development scenario and **b** constant cotton production development scenario. *Grey bars* represent average water use scenario, while error bars represent best and worst case scenario for the alternative irrigation methods

feedback mechanisms that result from such production losses (or gains for the drip irrigation case) if farmers compensate for the production loss/gain by increasing/decreasing the area of irrigation. The highest potential for water use reduction is in this case generated with drip irrigation (12 km^3/year) and alternate surge flow (11 km^3/year), see Fig. 11.2b. These two techniques have thus the highest water productivity. Alternate furrow and surge flow provides relatively small reductions of 6 and 3 km^3/year, respectively. The low-end value of the range for drip irrigation shows a reduction down to 17 km^3/year.

In particular, for irrigation methods with relatively low yield, such as the alternate furrow and surge flow irrigation, the constant-production scenario (Fig. 11.2b) implies that additional water is lost on extended irrigation areas that are needed to keep the cotton production unchanged. This extra water loss means that the benefits of using low-yield methods can be smaller (Fig. 11.2b) than implied by the constant-area scenario (Fig. 11.2a). Considering also uncertainties related to local climate and soil texture (error bars) our results suggest that a field-scale implementation of the surge flow method throughout the ASDB may in worst case increase the total water use, relative to the current use. The results of the surge flow method are relatively uncertain (as reflected by the large error bar), because of the diversity in results from available field studies. Fig. 11.2b also shows that the benefits of using high-yield methods such as drip irrigation can be larger than implied by the constant-area assumption of Fig. 11.2a. The alternate surge flow method seems to have potential for large water use reductions, but the result is based on just one field study (Horst et al. 2007).

The error bar ranges shown in Fig. 11.2 indicate that all alternative irrigation methods have a potential to reduce the water use in the ASDB by about 10 km^3/year, i.e. reducing the irrigation water use from about 30 km^3/year to 20 km^3/year. Our results show that this water use reduction would be approximately equally distributed between the two main sub-basins, i.e. the Syr Darya drainage basin and the Amu Darya drainage basin. Resulting reductions in irrigation water use in the Syr Darya drainage basin of about 5 km^3/year are almost as large as the present Syr Darya river discharge into the Aral Sea. Equally large water use reductions in the Amu Darya drainage basin would increase the freshwater availability in the whole Amu Darya delta. Such an increase in river flow would make reservoirs and lakes in the delta a more reliable and safer source for drinking water by reducing the variability of the volume and improving the water quality.

Spatial variation in salinity, not explicitly considered here, could affect the resulting cotton yield obtained from use of the alternative methods. According to Rajak et al. (2006), drip irrigation can increase the yield considerably more in soils with high salinity than in soils with lower salinity. The downstream regions in the ASDB closest to the Aral Sea are in general more affected by salinisation and poor water quality than the upstream regions, which means that drip irrigation can be a relatively beneficial alternative there. It has for instance been shown that excess irrigation water considerably elevates the groundwater tables in this part of the ASDB (Johansson et al. 2009), which in turn contributes to increased soil and groundwater salinisation. The use of water efficient drip irrigation systems mean that considerably less water can be applied to the irrigated fields, which may decrease the groundwater levels in this part of the ASDB and slow down the salinisation processes.

Within the ASDB, considerable water losses occur at the irrigated fields, during transport to/from irrigated regions and between fields within the irrigated regions, due to inefficient irrigations techniques and water distribution systems. The underlying assumption for the results presented in Fig. 11.2 is that the losses in the distribution system exhibit a 1:1 relation with the water losses over the irrigated areas. Although it is beyond the scope of the present study to investigate the dynamics of water losses in the distribution system, we consider in the following the effects of a conservative alternative case where the water losses in the distribution system are completely independent of the water losses over irrigated fields. Then here presented water reductions due to change of irrigation method would only apply to the fraction of water actually lost over the irrigated fields. For instance, if the losses in the distribution system are 30% (i.e. the average value for Central Asia as a whole; Bucknall et al. 2003), the actual water use reductions would equal to 70% of the values presented above. For instance, in this case, all alternative irrigation methods would have the potential to reduce the water use in the ASDB by about 7 km^3/year (compare with the value 10 km^3/year), which is still a considerable reduction.

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Part III
Recent Innovative Processes in Agricultural Production

Chapter 12
Use of Surface Modified Inorganic Nano Materials as Slow Release Nitrogen Fertilizer

Deepesh Bhardwaj and Radha Tomar

Abstract Laboratory batch experiments were conducted to investigate the sorption of nitrate from aqueous solutions using hydrothermally synthesized and surface modified zeolite nano particles. The ability of surface modification with hexadecyltrimethyl ammonium (HDTMA) and Dioctadecyldimethyl ammonium (ADOD) greatly enhance the sorption and slow release of nitrate. The slow release tendency of the modified materials has also been studied through Thin Layers in Funnels and Soil Column Analytical Test. The synthesized materials were characterized by different instrumental techniques viz. X-ray diffraction, FTIR, SEM, EDS, TEM, and TGA.

Keywords Slow Release Nitrogen Fertilizer • Removal of Nitrate • Inorganic Nano Material • Surface Modification • Hydrothermal Synthesis

12.1 Introduction

The demand of food grain is increasing at an alarming rate due to increasing population and decreasing cropping area. In order to meet the increasing global food demand, it is essential to increase the productive capacity of existing agricultural lands minimizing the yield losses due to pest and weeds, and through applying appropriate nutrients at proper times to the crops. This is to be done in an eco-friendly manner to assure that the crop yield per unit area is increased and the environment is conserved and not degraded. In this regards, agrochemicals have become a necessary evil in augmenting agriculture production and the environment. The increasing use of agrochemicals ultimately results in serious health and environmental problems which must be addressed to minimize the harmful effects. When these chemicals are applied to soil, only a small portion is utilized leaving behind the reserves

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of residues. These agrochemicals are subjected to sorption, degradation, runoff and leaching processes. Transport by runoff and leaching can result in contamination of surface and ground water (Carrizosa et al. 2003). The high solubility of chemical fertilizers exacerbates their tendency to degrade ecosystem, particularly through eutrophication. The accumulation of bioavailable plant nutrients like phosphorous and nitrogen in surface water leads to algae proliferation, an increase in oxygen demand, and deterioration of water quality and even decreases the waterways storage and transport capacity (Indiati and Sharply 1995; Lemunyon and Gilbert 1993; Sharply et al. 1993, 1996; Sims et al. 1998). The manufacturing, storage, and application of nitrogenous fertilizers cause green house gas emissions like nitrous oxide (N_2O). Ammonia gas (NH_3) may be emitted following application of inorganic nitrogenous fertilizers, manure, or slurry. Besides supplying nitrogen, ammonia can also increase soil acidity through releasing H ions after the nitrification process (lower pH, or "souring"). Excessive nitrogen fertilizer applications enhance vegetative growth leading to pest problems by giving the opportunity for better food and thus increasing the birth rate, longevity, and overall fitness of certain pests (Jahn et al. 2001a, b; Jahn 2004; Jahn et al. 2005; Preap et al. 2001, 2002).

Protecting water from agricultural pollution is a very complex process. The retention and mobility of a pesticide in soil is determined by the extent and strength of sorption reactions, which are governed by the chemical and physical properties of the soils and fertilizers involved. Zeolites could be the best environmental friendly material, which can solve many purposes related to agricultural pollution. The permanent negative charge (zeta potential) on zeolites enables them to be modified by cationic surfactants, which results in the enhancement of adsorption of organic pollutants. Under the surfactant bilayer configuration, the zeolite reverses its surface charge, resulting in a higher affinity for negatively charged anions, and the sorption and retention of anions are attributed to surface anion exchange. Because the surfactants are attached only on the exchange sites situated inside the pores, they are still available for cation exchange. Therefore, loading of cationic nutrients such as K in the pores can be achieved simultaneously with the anionic nutrients such as NO_3^- and PO_4^{-3} on their surface. The present work deals with the removal of NO_3^- from aqueous waste using synthetic inorganic ion exchangers (zeolites) and their surface modified forms of HDTMA (Hexadecyltrimethyl ammonium) and ADOD (Dioctadecyldimethyl ammonium). The modified materials are also examined as slow release nitrogen fertilizer. The effect of pH, exchanger composition, and surfactant concentration has also been studied.

12.2 Material Synthesis

For the proposed work two zeolites named SZC (synthesized zeolite clinoptilonite) and SZM (synthesized zeolite montmorillonite) have been synthesized by the hydrothermal method using a Teflon lined stainless steel pressure vessel and keeping it in a preheated (150°C) oven at autogeneous pressure and static conditions for 72 h. The starting materials used for the synthesis of zeolites are: the silica source was tetraethoxy silane $(C_2H_5O)_4Si$, the aluminium source used was aluminium nitrate $[Al(NO_3)_3]$, potassium nitrate (KNO_3) was used as source of potassium, and sodium hydroxide (NaOH) as template and alkali source. The materials were thoroughly characterized by using instrumental techniques viz. X-ray diffraction (XRD), Fourier transform infra red spectroscopy (FTIR), scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), transmission electron microscopy (TEM), and thermo gravimetric analysis (TGA).

Surface Modification, Preparation of Slow Release Nitrogen Fertilizer, and Sorption Studies A pre-weighted quantity of washed zeolite samples was mixed with HDTMA and ADOD solution prepared in ethanol/water (50/50). The concentrations of HDTMA and ADOD solutions used for the preparation of surface modification were 250 (HDTMA1 and ADOD1), 500 (HDTMA2 and ADOD2), 750 (HDTMA3 and ADOD3), and 1,000 mg/l (HDTMA4 and ADOD4). The suspension was shaken at room temperature for 24 h, centrifuged at the same temperature, washed with ethanol/water (50:50) and distilled water. The materials were then filtered and washed until the solution was Cl^-/Br^--free as determined by an $AgNO_3$ test. The resulting zeolites were then frozen and freeze-dried. The modified zeolites named SZC_{HDTMA}, SZC_{ADOD}, SZM_{HDTMA}, and SZM_{ADOD} were kept in closed bottles at room temperature until they were used.

To prepare slow release nitrate fertilizer, the required quantity of modified zeolite SZC_{HDTMA}, SZC_{ADOD}, SZM_{HDTMA}, and SZM_{ADOD} were placed in a shaker with 0.01-M solution of NH_4NO_3 for 24 h, then filtered, washed three times with deionized water, air dried, and kept in airtight containers. The solid–liquid ratio used was 1:10 for the synthesis of loaded zeolites. Similarly, nutrient loading was also done on unmodified zeolite to study the effect of surface modification on nutrient uptake capacity and slow release of nutrients as compared to surface modified zeolites (SMZ). The amount of NO_3^- sorbed was calculated from the difference between the initial and the equilibrium solution concentrations.

The sorption or exchange phenomena have been studied at different parameters. In most of the experiments (except weight variation study or sorbent dose), the aqueous phase to sorbent ratio was fixed as 1:4 (ml/mg) by taking 50 ml of the aqueous solution containing 14 mg/50 ml of ammonium nitrate and 200 mg of sorbent dose in an 150-ml conical flask. The concentration of nitrate in the aqueous system was determined on the basis of the formation of orange colored azo compound when nitrate reacts with sulfanilamide and then coupled with N-(1-naphthyl)-ethylenediamine dihydrochloride that is absorbed at 540 nm. All the experiments were carried out in duplicate and care has been taken to repeatedly centrifuge the solution at high speed to avoid any solid particles in the aqueous phase. The sorption data are reported in terms of distribution coefficient (K_d) by using the following equation:

$$K_{\mathrm{d}} = \frac{C_{\mathrm{i}} - C_{\mathrm{e}}}{C_{\mathrm{e}}} \times \frac{V}{W}\ (\mathrm{ml/g})$$

where,

C_i = Initial concentration of metal ions,
C_e = Concentration of metal ions after equilibration,
V = Volume of the solution in ml, and
W = Weight of the exchanger in g.

Sorption Isotherm The sorption isotherm was measured using the batch equilibrium method with initial concentration of NO_3^- ranging from 160 to 280 mg/l. The suspension was then shaken at 30°C ± 2°C for 24 h and then filtered, centrifuged at 15,000 rev min^{-1} (rpm) at the same temperature. Equilibrium concentration (C_e) was determined in the supernatant solution spectrophotometrically. The C_i and C_e were measured in the same analytical batch and the difference between them was assumed to be due to sorption on zeolites. The sorption isotherm was obtained by plotting the amount sorbed C_s mg/g versus equilibrium concentration C_e mg/l and fitted to the Freundlich model:

$$C_s = K_f C_e^{1/n_f}$$

where, C_s = concentration sorbed mg/g, C_e = equilibrium concentration, K_f and n_f are the Freundlich constants. If C_s is plotted against C_e, the slope of the line will give the values of $1/n_f$ and the intercept of the y-axis gives the value of K_f and is characteristics of the sorbate and sorbent system.

12.3 Results and Discussion

12.3.1 Material Characterization

The X-ray diffractograms have been recorded on Bruker Axs D-8 Advance X-ray Diffractometer (XRD) using Cu-Kα radiation to study the crystalline nature of atoms in the material. The diffractograms were recorded in the range of 2θ = 10–100 at a scanning speed of 0.75 times/step(s). The XRD patterns of the sample show maxima at 2θ = 26.0 and 24.2 for SZC and SZM which corresponds to d spacing = 3.42 Å and d spacing = 3.67 Å, respectively. On comparing the data of surface modified forms of SZC and SZM with those of unmodified forms it is observed that they closely resemble with each other, indicating that the structural integrity of material is retained on surfactant treatment.

The chemical composition of synthesized material was determined for metal ions Na, K, Al, Si, and O using EDS. A revealing feature in the synthesis of zeolite is the strong correlation between Si/Al ratio of the resulting crystals, the nature of the cation used, and medium of synthesis (Komarneni et al. 1987). The estimated values (Fig. 12.1) agree well with the weight percentage of these metals on the basis of their amount taken. The chemical composition of SZC is: $K_{0.89}Na_{3.10}Al_{3.56}Si_{35.58}O_{56.87}$ and SZM is: $Na_{10.50}Al_{19.09}Si_{14.44}O_{55.98}$ obtained from EDX analysis data (Fig. 12.1). From the TGA graphs 7.99% and 15.2% weight loss has been obtained in the temperature range of 40–200°C and 14.58% and 25.89% weight loss in up to 1,000°C. Zeolites are found to exhibit a typical infrared spectroscopic pattern. Strongest vibration at 950–1,250 cm^{-1} is assigned to T-O stretching and the next strongest band at 420–500 cm^{-1} is assigned to T-O bending mode (T = Si or Al). The stretching modes are sensitive to the Si–Al composition of the framework and may shift to a

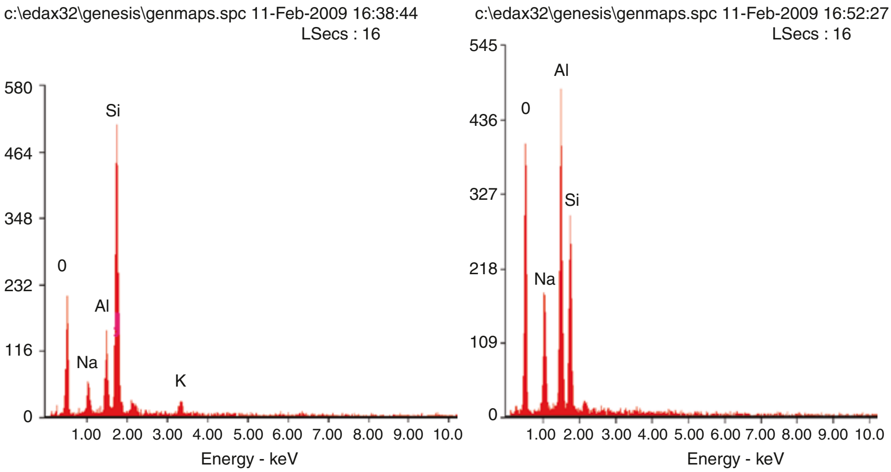

Fig. 12.1 Energy dispersive spectrometric analysis of SZC and SZM

lower frequency, while the bending mode may be related to the linkages between tetrahedral units. The major peaks appeared in unmodified zeolites, were compared with that of modified zeolites and found almost similar to each other, indicating the structural stability of the sample. Organo zeolite, in contrast to unmodified zeolite, has two intense bands around 2,850 and 3,000 cm^{-1}, which are assigned to asymmetric and symmetric stretching vibration of C–CH_2 of the alkyl chain, respectively (Bansiwal et al. 2006). The TEM observation shows that the nano size crystals can be obtained by the hydrothermal synthesis method. The TEM images of SZC and SZM show a nano particle size 15–20 nm. The SEM micrographs (Fig. 12.2) also confirm that the materials are purely crystalline in nature and the disordered structure shows the presence of cages or cavities that take part in sorption processes when exchangeable ions or complex molecules get adsorbed.

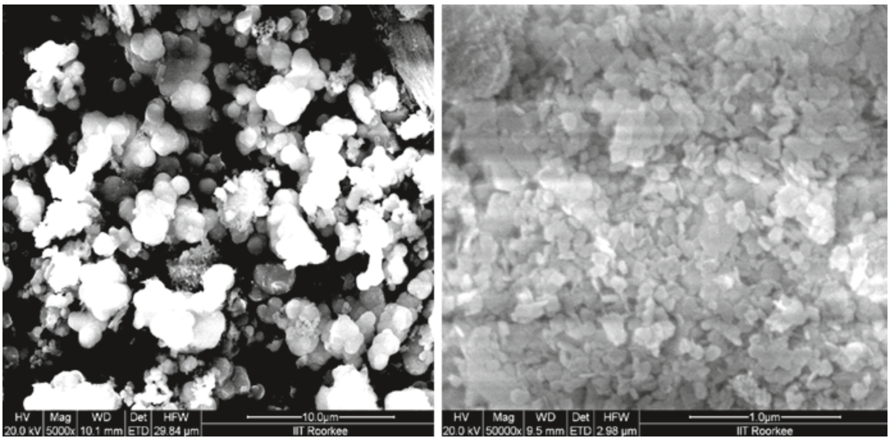

Fig. 12.2 SEM micrograph of SZC and SZM

12.3.2 Sorption Studies of NH_4NO_3

The batch technique is used to measure the sorption of NO_3^- on unmodified and surface modified zeolites (with HDTMA and ADOD) taking liquid–solid ratio (1:4) and the initial concentration of NH_4NO_3 as 14 mg/50 ml. To explore the best condition for the sorption of NO_3^-, studies were conducted by changing one parameter and keeping the others stable. Experimental results are described below. To find out the optimum pH for the sorption for NO_3^- on different modified and unmodified zeolites, sorption studies have been carried out. These studies were conducted at pH 3, 5, 7, 9, and 11. The results (Fig. 12.3) suggest that the sorption of NO_3^- increases with increasing pH values up to pH 7 and then it decreases due to the competition between NO_3^- and OH^- ions for the positive charged sorbent sites. The solubility also changes with the change in pH, which can influence the sorption. The increase in the liquid to solid ratio from 1:1 to 1:4 resulted in an increased sorption percentage of nitrates. Figure 12.4 clearly illustrates that with the increasing amount of sorbent from 50 to 200 mg, sorption of nitrate increases for all zeolites, which indicates that the sorption depends upon the availability of binding sites for nitrate. To find out the maximum time for the attainment of sorption equilibrium, the studies were performed for 3, 5, 7, 9, and 24 h. The result suggests that a maximum equilibration time of 12 h is required to attain the equilibrium (Fig. 12.5). The plots of sorption

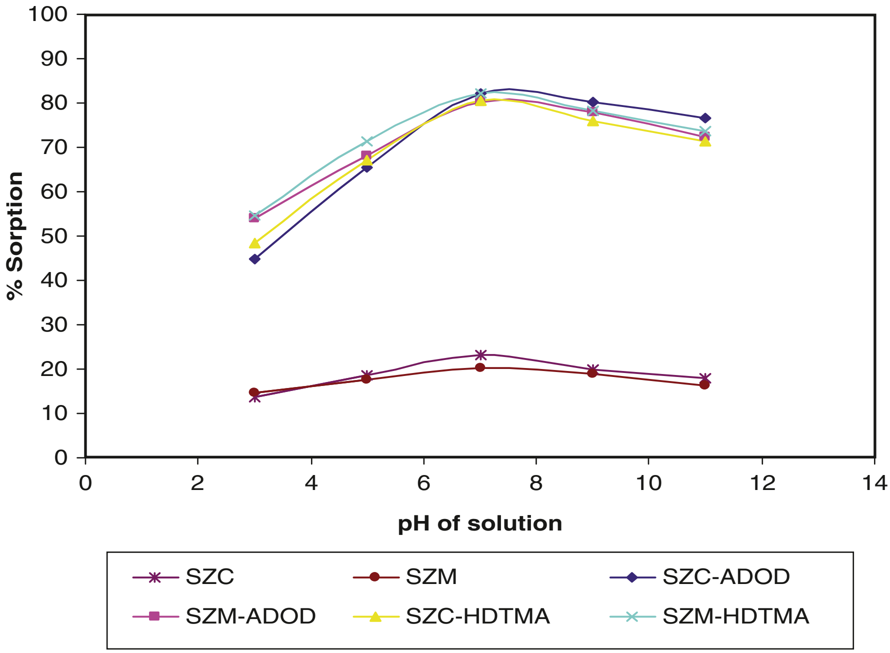

Fig. 12.3 Effect of pH of solution on sorption of NO_3^-. Weight of sorbent: 200 mg. Initial concn. of NH_4NO_3: 14 mg/50 ml. Temperature: 30°C. Equilibration time: 24 h

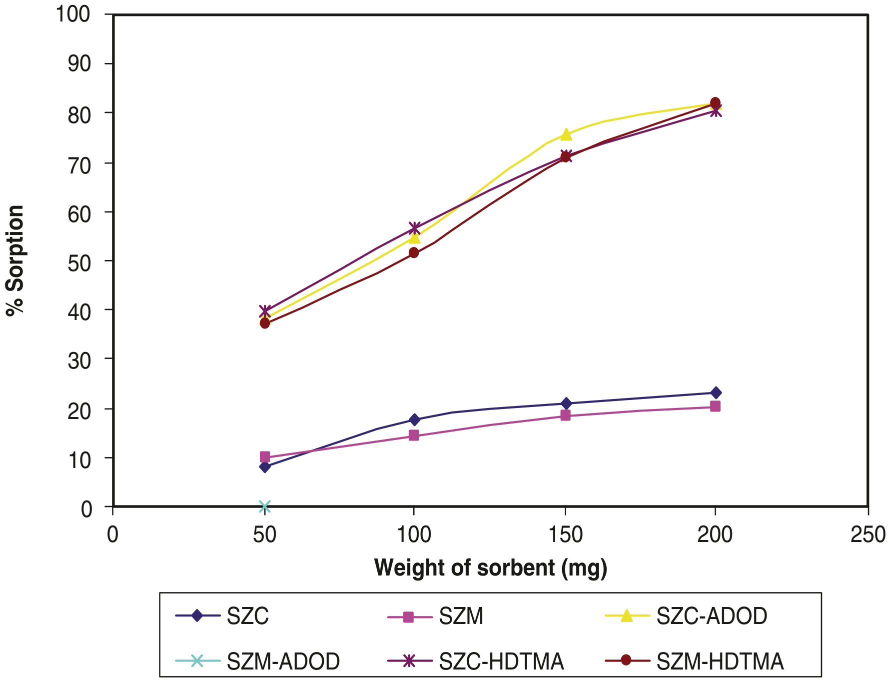

Fig. 12.4 Effect of sorbent dose on sorption of NO_3^-. Initial concn. of NH_4NO_3: 14 mg/50 ml. Temperature: 30°C. Equilibration time: 24 h. pH: neutral

percentage versus time indicate that sorption becomes asymptotic to the time axis representing nearly an equilibrium pattern. Figure 12.6 shows the effect of HDTMA and ADOD loading concentrations in a range of 250–1,000 mg/l on nitrate sorption. The percentage of nitrate sorption increases initially with HDTMA and ADOD loading and shows a maximum value at HDTMA4 and ADOD4, which corresponds to 1,000 mg/l of loading solution. This initial concentration exceeds the critical micelle concentration of the surfactant. It is, therefore, envisaged that these micelles attach as such of the external surface and then rearrange to form bilayers that tend to impart anionic characteristics (Bowman et al. 2000). Both the surfactants are more hydrophobic due to its carbon chain length. When zeolite is treated with high concentrations of surfactant, it exists as micelles with the hydrophobic end pointing outwards; these micelles have less affinity for water than the zeolite surface and therefore get adsorbed. These micelles then rearrange to form well-defined bilayers on the zeolite surface. When zeolite is treated with low concentrations of surfactants they form a monolayer on the zeolite surface and a bilayers system with high concentration. This increases the sorption of oxyanions (Kumar et al. 2007). The increase in temperature from 30°C to 50°C results in a decrease of sorption percentage after 40°C. It was found that the percentage of nitrate sorption increases when the temperature is increased to 40°C; however, when the temperature is increased further, the sorption decreases probably due to the change in energy of sorption or

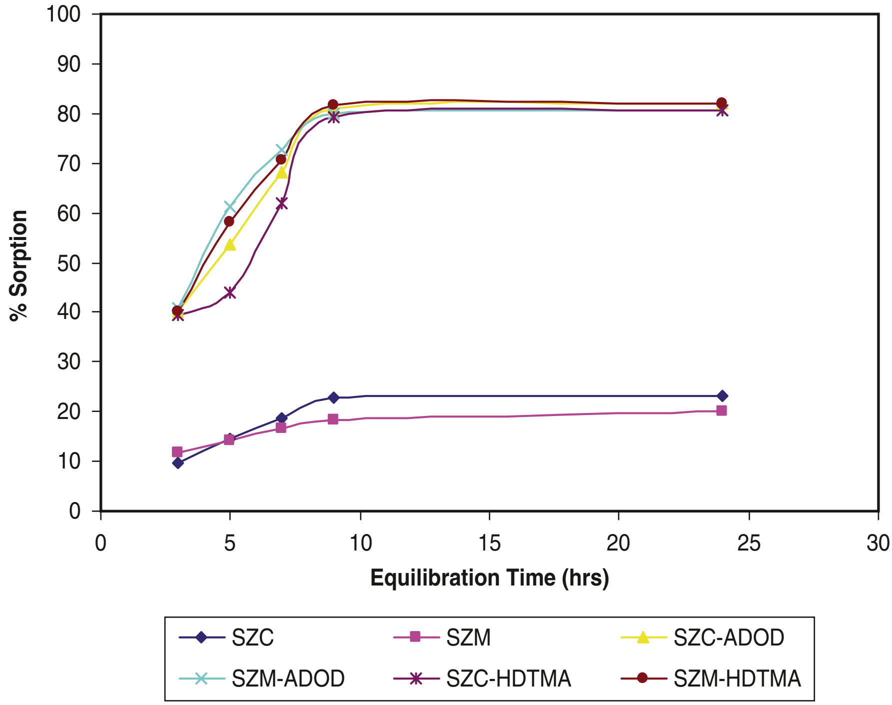

Fig. 12.5 Effect of equilibration time on sorption of NO_3^-. Weight of sorbent: 200 mg. Initial concn. of NH_4NO_3: 14 mg/50 ml. Temperature: 30°C. pH: neutral

weakening of attractive forces or charge in solubility of nitrate. Thermodynamic parameters, i.e., standard free energy change ($\Delta G°$), enthalpy ($\Delta H°$), and entropy ($\Delta S°$) all vary with the thermodynamic equilibrium constant (K_0) and were calculated using standard equations:

$$\Delta G^{o} = -RT \ln K \text{ or } -2.303RT \log K_0 \tag{12.1}$$

$$\log K_2/K_1 = \Delta H^{o}/2.303\ R[1/T_1 - 1/T_2] \tag{12.2}$$

$$\Delta S^{o} = \Delta H^{o} - \Delta G^{o}/T \tag{12.3}$$

$$K_0 \text{ (distribution coefficient) } = C_s/C_e \tag{12.4}$$

where, R and T is the universal gas constant and absolute temperature, respectively. The free energy of the ion exchange reaction has usually a negative value (Sherry 1968; Tagamil et. al. 2001; Wang et al. 2008). The sorption behavior of the synthesized material will be explained on the basis of sorption data in terms of the distribution coefficient (K_0) and thermodynamic parameters. The negative values of Gibbs free energy demonstrate the feasibility and spontaneity of the sorption process and

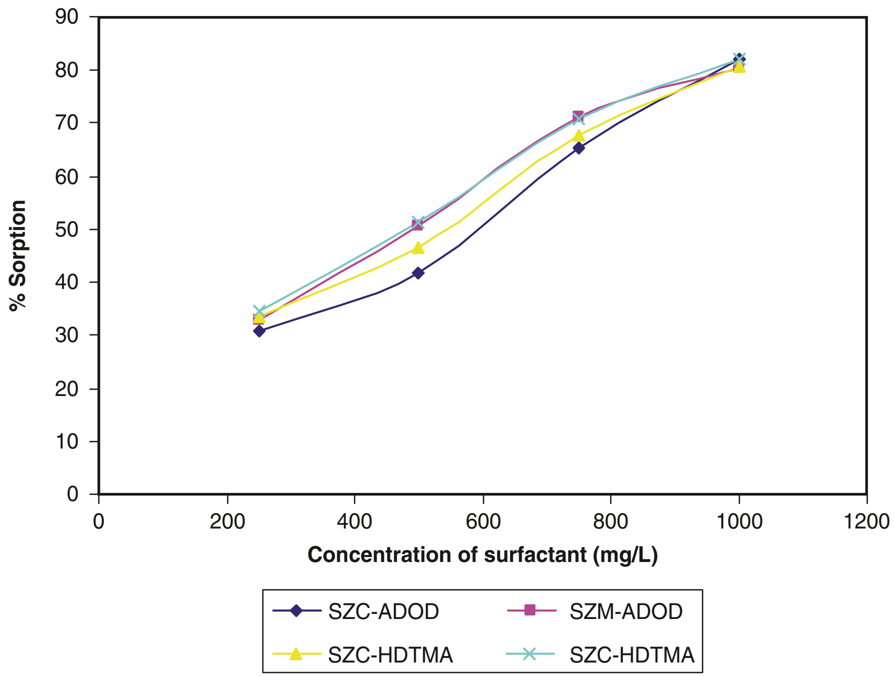

Fig. 12.6 Effect of concentration of surfactant on sorption of NO_3^-. Weight of sorbent: 200 mg. Equilibration time: 24 h. Temperature: 30°C. pH: neutral

the positive (ΔH°) value specifies the endothermic nature of sorption. The positive values of (ΔS°) indicate an increase in the randomness or disorder at the solid–solution interface during sorption.

12.3.3 Sorption Isotherm

The sorption isotherm is generally used for the design of sorption systems. A sorption isotherm was measured using the batch equilibrium method. If C_s is plotted against C_e, the slope of the line will give the values of $1/n_f$ and the intercept of the y-axis gives the value of K_f and is characteristic of the sorbate and sorbent system (Fig. 12.7). As K_f (mg/g) coincides with C_s when $C_e = 1$, that parameter can be considered as measure of relative sorption capacity to compare diverse sorbent systems. The value of K_f (mg/g) can be taken as a relative indicator of sorption capacity, while $1/n_f$ shows the energy or intensity of sorption. These are the experimental parameters, which depend on the sorbate and sorbent system. The applicability of the Freundlich sorption isotherm was also analyzed.

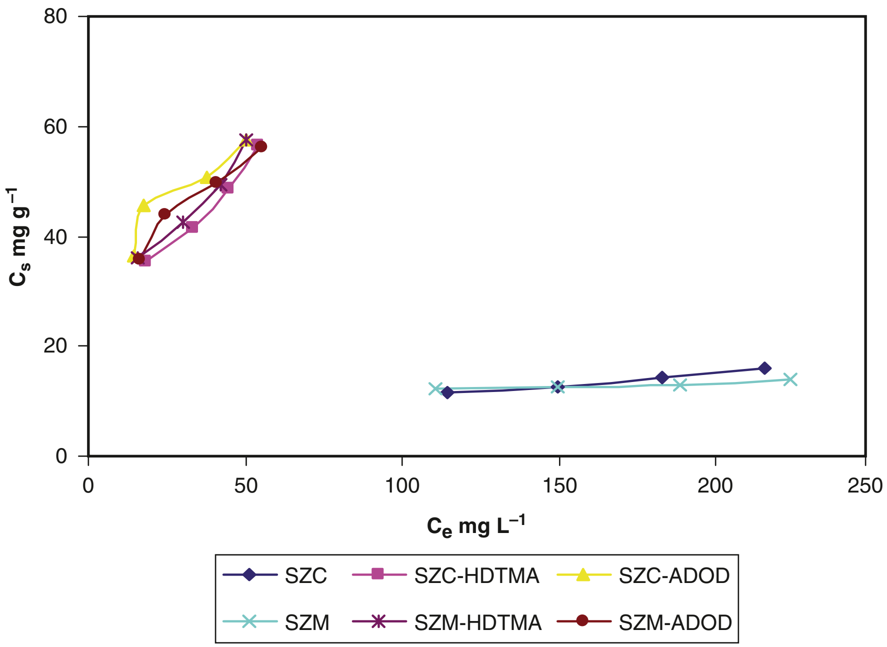

Fig. 12.7 Freundlich sorption isotherm for NO_3^-. Weight of sorbent: 200 mg. Equilibration time: 24 h. Temperature: 30°C. pH: neutral

12.4 Controlled (Slow) Release Studies

The studies of immobilization of plant nutrients like phosphate and nitrate from water have been attracting more and more research interest in recent years to reduce the excess use of nutrient, which leads to environmental problems. To access the use of zeolites and surface modified zeolites as slow release fertilizers, two types of leaching studies have been performed:

1. Thin Layers in Funnels Analytical Test
2. Soil Column Analytical Test

The materials taken for slow release studies have been hydrothermally synthesized SZC and SZM modified with HDTMA4 and ADOD4 (1,000 mg/l). The slow release formulations were prepared as described above.

12.4.1 Thin Layers in Funnels Analytical Test

The 2 g of modified and unmodified zeolite (SZC_{HDTMA4}, SZM_{HDTMA4} and SZC_{ADOD4}, SZM_{ADOD4}) were deposited on filter paper inside a Buchner funnel (5 cm diameter) and the standard solution (25 ml) of commercial NH_4NO_3 (0.01 M) was sprayed on a very thin layer, approximately 0.5 cm in thickness, of SZC, SZC_{HDTMA4}, SZM, SZC_{ADOD4}. The funnels were carefully irrigated after 24 h with 50 ml of water by adding 10 ml every 30 min. The leachate was collected after irrigation and the leached nitrate concentration was determined spectrophotometrically.

12.4.2 Soil Column Analytical Test

The soil columns were made by using 25 ml burette and the water was continuously added at a flow rate of 50 ± 1 ml/day with the help of a 50 ml burette, inside the first column 10 g of soil over laid with 2 g of SRF (slow release fertilizer of nitrate) was placed. The leachates were collected to determine the concentration of nitrate using the UV-Vis Spectrophotometer. Three columns were placed simultaneously SRF, prepared from unmodified and modified zeolite and with pure fertilizers (NH_4NO_3). A thin layer of glass wool was also placed on top of the soil column to maintain a homogeneous surface during the irrigation. The leaching studies have been conducted for 15 days.

12.4.3 Results of Controlled Release Studies

12.4.3.1 Thin Layer in Funnels Analytical Test

The results of the Thin Layer Funnels Analytical Test clearly indicate that the hydrothermally synthesized material SZC and SZM modified with HDTMA and ADOD can be used as slow release formulations, due to their greater tendency to hold (Li and Bowman 1997, 1998; Li et al. 1998; Sullivan et al. 1998) the plant nutrients (nitrate) and also release them slowly. Unmodified zeolite releases around 25–35% of nitrate and phosphate after the first irrigation, whereas more than 55% of nutrients were leached out from control soil. More than 75% of applied nutrients are leached out after the 6th irrigation in case of soil. On the other hand, surface modified zeolite shows its slow release tendency with only 15–20% of leaching after the first irrigation and around 40% after the 6th irrigation and still shows nearly 4% leaching after the 24th irrigation which suggests its slow release capacity. Results are represented in Table 12.1.

12.4.3.2 Soil Column Analytical Test

The percolating system with soil and without these herbicide and fertilizer did not provide any detectable amount of NO_3^-; therefore, all the measured concentration

Table 12.1 Thin Layer Analytical Test desorption of NO_3^-

Material	% desorption				
	1st irrigation	3rd irrigation	6th irrigation	12th irrigation	24th irrigation
Soil	69.1	26.3	14.1	0	0
SZC	48.6	21.1	11.5	0	0
SZC_{HDTMA}	20.9	9.6	3.5	2.6	2.2
SZC_{ADOD}	21.6	9.4	3.9	2.9	2.3
SZM	45.7	23.6	13.4	0	0
SZM_{HDTMA}	22.8	8.6	4.6	3.4	3.1
SZM_{ADOD}	25.7	9.8	4.9	2.8	3

Weight of adsorbent: 2 g. Temperature: 30°C. Initial concn. of NH_4NO_3: 0.01 M. Irrigation rate: 50 ml (10 ml/30 min). Desorbing reagent: distilled water

Table 12.2 Soil Column Analytical Test desorption of NO_3^-

Material	% desorption							
	Day 1	Day 2	Day 3	Day 5	Day 7	Day 10	Day 13	Day 15
Soil	61.3	30.7	21.8	11.2	3.4	0	0	0
SZC	35.4	24.6	13.6	6.3	4.7	3.6	0	0
SZC_{HDTMA}	17.3	12.8	7.9	6.8	4.6	4.2	3.6	2.9
SZC_{ADOD}	19.7	11.2	8.7	5.4	5.7	3.4	3.9	3
SZM	30.8	18.2	12.1	9.7	7.4	5.3	0	0
SZM_{HDTMA}	17.9	10.9	7.9	4.6	4.5	4.5	4.1	3.5
SZM_{ADOD}	18.5	11	8.5	5.2	4.9	4.9	3.9	3.1

Weight of adsorbent: 2 g. Temperature: 30°C. Weight of soil: 10 g. Desorbing reagent: distilled water. Initial. concn. of NH_4NO_3: 0.01 M. Irrigation rate: 50 ml/day

of NO_3^- from leachates obtained from the percolating system having soil plus slow release formulations can be attributed to the fertilizer source exclusively. The results are shown in Table 12.2. It can be seen from the data that at the start of the experiment (day 1) a maximum desorption percentage of 61% (NO_3^-) is observed for soil, between 30% and 35% desorption is observed for SZC and SZM for NO_3^- but in case of surface modified slow release formulations it is below 28%. Furthermore it can be seen that in the initial stage, dissolution of NO_3^- from all seven formulations including soil occurs rapidly and attains a desorption around 7% after day 7, after which slow release is only observed for SRF (slow release fertilizers) until day 15.

12.5 Conclusions

Slow release fertilizers are excellent alternatives to soluble fertilizers. Because nutrients are released at a slower rate throughout the season, plants are able to take up most of the nutrients without waste by leaching. A slow release fertilizer is more convenient, since less frequent application is required. Zeolites, after surfactant treatment with HDTMA and ADOD, can be utilized as slow release fertilizer and efficient sorbent for these agrochemicals, and the extent of sorption increases with the increasing surfactant loadings. The two synthesized zeolites SZC and SZM have shown the highest sorption capacity after modification with surfactant and indicate their possible use as controlled release fertilizers in India where food demand is increasing drastically and also for the sake of environment protection from these agrochemicals.

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Chapter 13
Organic Fertilizer Use in Northeastern Thailand: An Analysis of Some Factors Affecting Farmers' Attitudes

Seksak Chouichom and Masahiro Yamao

Abstract The transition to environmentally friendly farming practices and products has recently become popular among farmers and consumers throughout the world. Organic farming using natural fertilizers has gained acceptance albeit slowly in many developing countries due to some socio-economic constraints. This study therefore investigated the opinions and attitudes of jasmine rice farmers in Surin province, northeastern Thailand towards the use of organic fertilizers in their farms. Information was collected from 100 rice farmers whose socio-economic profiles and attitudes were determined through interviews and the use of the Likert's scale, respectively. Pearson's correlation coefficient (r) statistics was employed to correlate the two variables. Among the variables measured, age of farmers, educational attainment, and degree of extension worker contact were found to be strongly correlated with positive attitudes towards the use of organic fertilizers at the 5% level. It can be concluded that adoption of organic farming practices among the respondents is closely associated with the availability and access to information about organic fertilizers as well as farmers' perceived maturity with age. For the promotion of organic fertilizer use, there must be a more intensive information campaign using all available possible means.

Keywords Field Survey • Manure • Rice Cultivation • Socio-Economic • Sustainable Agriculture • Surin Province

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13.1 Introduction

Thailand is a leading agricultural country with rice as the major export crop involving around 60% of the population who are farmers in the rural regions of the country. All these years, Thai rice farms have been heavily dependent on fertilizer use and therefore, fertilizer costs account for a significant portion of total farm capital investments. Unfortunately, domestic fertilizer requirements cannot be met fully and must therefore be supplemented with chemical fertilizers, especially those imported from overseas. The world price of Diammonium Phosphate (DAP), for example, has almost tripled from US$ 252 per t in January 2007 to US$ 752 per t in January 2008 (IFDC 2008). In 2007, Thailand imported agricultural chemicals such as fertilizers amounting to 3,684,179 t (35.3 billion ThB, US$ 1 = 35 ThB). In 2008, the amount increased to 4,328,296 t (45.9 billion ThB) to fulfill its domestic requirement (OAE 2008). This figure increases every year because of continuing demands for fertilizers in response to increasing rice production as dictated by export targets. As a consequence, local fertilizer prices will remain high for some time as long as supply remains limited.

Farms around the world have historically used chemical fertilizers for a long time, and the increasing demand for such fertilizer and their short supply drive up their market prices. It therefore becomes imperative to identify cheaper, easily sourced alternatives such as organic fertilizers to address this problem. In addition, chemical fertilizers are known to cause many environmental problems and their continued use has impacted on farm ecological systems and soil structures. These adverse ecological impacts coupled with increasing global prices and diminishing supply for fertilizers, potential hazardous effects on human health, and inferior final rice product quality all contribute to the renewed promotion of the use of organic fertilizers in Thai farms in recent years. The continued use of expensive chemical fertilizers by Thai farmers also presents added economic hardships among marginal farmers as Thai soil scientists predicted that the fertilizer price will remain high for at least a few more years. For these reasons, organic fertilizers have an important role for alleviating such economic and environmental problems and also help to increase agricultural productivity as well as reduce the total cost of farm production (Antarikanon 2000).

When used in reference to fertilizers, the word organic generally means that the nutrients contained in the product are derived solely from the remains or by-product of biological organisms, cotton meal, blood meal, fish emulsion, manure, and sewage sludge. Urea is a synthetic organic fertilizer, i.e., an organic substance manufactured from inorganic materials (Reft 1990). Overall, organic fertilizers can slowly replace chemical fertilizers which can potentially translate into significant cost savings for farmers, reduce chemical fertilizer dependence and imports, and can also be beneficial for the environment, particularly farm systems leading to a sustainable agricultural future (Siriphongsaroj 1989).

The Thai government through its different agricultural extension and research agencies has come up with many ways aimed towards increasing the agricultural productivity of Thai farmers in recent years. The goal to improve agricultural productivity and sustainability in the long term can be achieved partly with the promotion of more organic fertilizer use to replace the traditional chemical fertilizers currently in use (Sartsanarakgij 2009). However, the acceptance of organic fertilizers among Thai rice farmers is a slow process with many inherent problems of socio-economic and technical nature. This study therefore focuses on examining empirically some of these possible socio-economic factors influencing positive opinion towards organic fertilizer use among rice farmers in Surin province, northeastern Thailand. In addition, the specific objectives of the study are to analyze farmers' attitudes towards organic fertilizer use, determine the relationship between farmers' attitudes and their socio-economic background, and identify some causes and problems that prevent some farmers from using organic fertilizers.

13.2 Methodology

13.2.1 Study Area

The survey of this study was conducted in Muang district of Surin province which has a land area of 8,124.056 km^2 in northeastern Thailand. The area allocated to rice farming amounted to 3,172,132 Rai (1 Rai = 1,600 m^2) or around 71.52% of the entire provincial agricultural land (3,631,421 Rai) in 2008. Surin has the 10th largest population among 76 Thai provinces, being 1,404,252 persons. This province is divided into 17 districts (Amphoe) with 158 subdistricts (Tambol) consisting of 2,119 villages (Moobaan). The number of farming households was 189,139. About 92.8% of the total population lives in the rural area, most of whom were doing rice farming.

13.2.2 Data Collection

The research was carried out in September 2008 following the pretest conducted one month earlier. The sample size in this research was 100 farmers who were engaged in rice cultivation from whom the opinions about organic fertilizer use were obtained. The study employed a semi-structured and structured questionnaire. In order to complement both quantitative and qualitative data, more information was collected through focus group discussion. This analysis used population-based survey to determine the opinion of farmers about organic fertilizer use. Interviews were conducted on the farm site or in the farmers' households. The interview schedules were composed of open-ended and closed questions but some questions elicited quantitative data as well. The modified interview schedule includes 18 statements of opinions regarding organic fertilizer use. The received responses were scored on a five-point Likert's scale ranging from "strongly agree (5)" to "strongly disagree (1)".

13.2.3 Data Analysis

The data were analyzed with the Statistical Package for the Social Sciences (SPSS) for Windows (SPSS 2004). Descriptive statistics was applied to analyze percentage, arithmetic mean, and standard deviation. Pearson's Correlation Coefficients (*r*) statistics were computed to explore farmers' attitudes towards organic fertilizer use. A significance of $p < 0.05$ was set for statistical analyses.

13.3 Results and Discussion

13.3.1 Demographic Characteristic of Rice Farmers

As shown in Table 13.1 the average age of farmers was 52.3 years; most of the farmers in the area were old male farmers, were able to read and write, and also sign their names. The majority of the farmers finished higher levels (5.2 years) than the Thai standard compulsory school years at that time (primary school grade 4). The number of hired labor annually was 2.6 man crops. Most of the rice farmers usually find extraordinary jobs during the off-season such as construction labor, cutting sugarcane, rice harvesting, and silk weaving in Surin and neighbor areas. The average farm area of organic farmers was 22.87 Rai (1 Rai = 1,600 m^2), they used two wheel tractors and small water pumps as convenient agricultural devices for their agricultural activities. Their average total income was 60,258.25 ThB/year (1 US$ = 35 ThB) which is below the national average of 62,300 ThB, resulting in rural farmers moving to big cities to seek alternative jobs and earn more income to support their families.

Table 13.1 Demographic characteristic of rice farmers

Demographic characteristic	Mean (100 farmers)	Correlation coefficient (*r*)
Age (years)	52.3	0.30*
Education (years)	5.2	0.28*
Laborers in farm (man crop)	2.6	0.17
Family members (persons)	3.8	0.15
Farm area (in Rai, 1 Rai = 1,600 m^2)	22.87	0.22
Total annual income (ThB/year, US$ 1 = 35 ThB)	60,258.25	0.14
Total cost in farm (ThB/crop)	27,498.48	0.20
Experience with farm (years)	25.2	0.19
Extension worker contact (times/year)	11.8	0.29*
Organizational participation (times/month)	0.64	0.20
Credit availability (times/month)	0.46	0.18

* Significant at 0.05 probability

Besides, the farmers had experience with rice farming for about 25.2 years; they contracted agricultural extension workers about 11.8 times a year, while radio and television were communications media from where they usually receive all information. The budget for their farm is around 27,498.48 ThB a crop, the big portion of which was spent for agricultural activities. They attended agricultural organizations like Bank for Agriculture and Agricultural Cooperatives (BAAC), organic rice farming groups, One Million Community Fund, agricultural cooperatives at an average of 0.64 times/month, as well as accessed credit facilities around 0.46 times/month.

13.3.2 Organic Fertilizer Use

From the field surveyed and farmers interviewed, 81% stated that most organic fertilizers that they use came from cow's manure, and 75, 67, 60, 54, 47% came from manure of buffalo, elephant, swine, chicken, and duck, respectively. A high number of farmers (73%) indicated that organic fertilizers are fermented and mixed manures together with husk, bran, molasses, EM (Effective Microorganisms), and water as soil extension workers have suggested processing these for about one month before application on rice farm. But some of the farmers still lack information on technique, time, and proportion of organic fertilizer application, etc. It so happened that farmers were relying on what their neighbors were practicing, thus explaining many imprecise methods observed. Therefore, the quality of techno-transfer and extension service given by agencies to rice farmers needs to be improved to better access relevant information of the farmers on the successful use of manure, for example.

Farmers should also be encouraged to obtain essential knowledge on some basic aspects of plant nutrition, and how these are related to fertilizing requirements (McGuiness 1993). The precise mixture of manure, means, timing, and ratio are all important factors to obtain maximum plant yield. Improper organic fertilization, manure utilization, or soil improvement often lead to wasted natural resource, causing water pollution, and eventually destroying the soil (Odhiambo and Magandini 2008).

In terms of manure use of farmers, more than four out of five (81%) of farmers applied organic fertilizer. The rice farmers use their farmyards to ferment organic fertilizer. Over 60% of rice farmers pointed out that the manures were always easily accessible when required. Also around 53% of farmers said that they knew when and how to put on organic fertilizer to their rice farm. Most of the rice farmers in Surin province kept livestock, particularly cows and buffalos. They used manure from their animals but the amount of manure was often not enough implying that farmers had very few animals. They need to buy from their farm neighbors and some of the farmers bought manures from commercial farms that are usually quite far away. As such, the amount of manure utilized by the farmers may be limited due to concerns of high transportation costs. In case of farmers who use manure from their own livestock, manure from small household areas is often of poor quality because of the low quality of grazing available to cattle (Nyamangara et al. 2001). Likewise, the use of manure is limited by many factors. Because the demand for land intended for crop production increased, with human population growing, livestock are often removed and relocated away from the villages. One of the obstacles for manure use are the limited transportation facilities from livestock farm to rice fields (Kaliba et al. 2000).

13.3.3 Farmers' Attitudes Towards Organic Fertilizers and Their Use

Table 13.2 showed the attitudes of farmers towards organic fertilizer and their use. We found that the farmers in the study area expressed a moderately good opinion towards organic fertilizer and the farmers tend to accept and utilize organic fertilizer steadily. This suggests that the growing adoption of manures as compost has

Table 13.2 Farmers' attitudes towards organic fertilizers and their use

Statements on farmers' attitudes towards organic fertilizers and their use	Attitude		
	Mean	S.D.	Level
1. Organic fertilizer can decrease weed quantity and chemical use	4.16	1.02	Agree
2. Organic fertilizer use can conserve soil humidity	4.03	0.84	Agree
3. Using organic fertilizer manure could decrease soil erosion and increase soil nitrogen fixation	4.11	0.91	Agree
4. Organic fertilizer use can cause soil turn loamy and thus make soil preparation and plowing easy	4.49	0.75	Strongly agree
5. Organic fertilizer use can increase rice production and quality of rice	3.98	0.68	Agree
6. Organic fertilizer use can cause lower farm investment	4.01	0.87	Agree
7. Organic fertilizer use can help the environment better	4.14	0.56	Agree
8. Organic fertilizer use can increase organic matters in soil	4.11	0.77	Agree
9. New manure can be used for farm fertilization immediately	3.22	1.13	Neutral
10. Plowing rice stubble and weed stalk can increase organic matter in soil	4.09	0.95	Agree
11. Soil structure is mellow and pliable	4.08	1.12	Agree
12. Soil structure is tight and firm	2.51	0.73	Disagree
13. Soil structure is same as before	2.73	0.89	Somewhat
14. The percentage of broken rice seeds decreased	4.21	0.96	Agree
15. The percentage of broken rice seeds increased	2.63	1.16	Somewhat
16. The percentage of broken rice seeds has not changed	2.56	1.05	Somewhat
17. Pests and insects increased	2.58	1.06	Disagree
18. Rice plants are strong to resist diseases and insects	3.67	0.69	Agree
Total	3.62	0.89	Agree

resulted in increasing organic fertilizer utilization, which may explain the slowly increasing rice yield. Regarding farmers' opinions about organic fertilizer we also noticed that when they use organic fertilizers, weeds and insects in the farm could be reduced. Many rice farmers will add organic fertilizer shortly before rice planting and after 1 month into the rice growing season. Thus, soil in farms employing organic fertilizers could absorb more organic nutrients and conserve water humidity. This is especially so when they use organic fertilizer constituted by manure of cow, buffalo, elephant, chicken, swine and so on, and when farmers put organic fertilizer quantity following the suggestion of the extension worker. Piles of compost turned into organic fertilizer are often accumulated beside their houses and in the rice farms.

The value of organic fertilizer will rely on blending material with the manure and other compost materials.

Moreover, we also found that the farmers agreed that using organic fertilizer manure could decrease soil erosion and increase soil organic matter. Farmers also concurred that organic fertilizer use could help soil become loamier and thus easier to plow. Basically, soil organic matter provides absorptive space for nutrients and water. Soil organic matter strongly affects the various properties of soil and can enhance main biochemical cycles. Interestingly, there exists a strong relationship between soil fertility and land productivity (Manlay et al. 2007).

Farmers also expressed their viewpoints that they could reduce farm expenditure by producing and mixing their own organic fertilizer for use in their farms. In fact, the farmer themselves produce organic fertilizer by using animal manures such as those mentioned above and by maintaining compost piles. Farmers had a moderately positive idea that fresh manure or organic fertilizer could be utilized immediately. Many of them believe erroneously that it was better to use fresh and dry manure for producing organic fertilizer. If the farmers allow manure to dry under natural light, essential nutrients could be lost. If farmers store manure for long periods, nitrogen in manure could be lost in the form of ammonia gas (Teaumroong 2005). They therefore allow organic fertilizer to ferment only for a month before applying these on their rice fields. A lot of Thai rice farmers in the study area, nonetheless, utilize organic fertilizer for rice planting without undergoing the one-month fermentation step. It becomes important for soil extension workers to instruct rice farmers how to prepare and apply organic fertilizer correctly.

In addition, farmers said that they could increase quantity and quality of rice production by adding organic fertilizer following the advice of soil extension workers. In less fertile soils, farmers utilized more organic fertilizer. For example, 1 t of organic fertilizer per hectare improved banana yield by 10%, and organic fertilizer increases soil organic matter in the long run. Yamano (2008) also showed that the application of organic fertilizer by Ugandan households raising improved cattle is higher than other households at over 500 kg/ha. Improved cattle are defined as crossbreeds of European and African cattle. Being highly prized breeds, they graze in confined fields making manure collection easier. On the other hand, local cattle are left in open fields to graze. As such, manure collection is difficult and results to lower manure quantity available for fertilization. Those farmers with local cattle or no cattle only apply manure amounting to 208 and 132 kg/ha, respectively. Expectedly, those with imported cattle can harvest about 182 bunches of bananas/ha, while other households only get about 130 bunches/ha.

Additionally, rice farmers felt that some farm organisms such as herbivorous fish were more likely to increase with organic fertilizer. Farmers noted that small fish hibernate in the watery field filled with molasses that have been left to ferment for 3 or 4 months to create organic fertilizer. Beneficial insects can help with pest management by controlling harmful insects. As a result of all these, rice yield can compare to higher levels associated with chemical use, with the costs kept to a minimum.

Furthermore, rice farmers believed that organic fertilizer use could enhance soil organic matter in the soil by using various kinds of agricultural wastes. Many farmers agreed that if they plow rice stubble and weed stalks before actual rice planting, they could produce more soil organic matter for their farms. However, some farmers burn straw and rice hay before planting. Those who do explained that it is easier to till the soil and that it contributes to savings in fuel and time.

The National News Bureau of Thailand (2003) reported that using feeds such as dried leaves plus a minute amount of fertilizer and applying them to rice fields had shown promising results in increasing the rice quality while lowering farming costs. Hay used in their experiments was sprayed with fertilizers and microorganisms and allowed to ferment. The new technique employs no chemicals but merely uses 30% of the common fertilizer. In a recent study comparing the costs and output of rice farming using conventional and organic methods, Chouichom and Yamao (2010) reported organic farming costs to be ThB 24,450.36/Rai, while conventional methods are more expensive at ThB 36,741.91/Rai. Comparing harvests and market prices, however, the results are not significantly different: conventional farmers harvest 454 kg/Rai which fetches a market price of ThB 16/kg for unmilled rice, while organic farmers realize 448 kg/Rai which is sold at ThB 19/kg. While differences in rice market prices do not vary greatly between organic and conventional rice, it seems that the difference in farming costs cited above is one of the most influential factor determining farmers' choice of organic farming.

Farmers observed that after using organic fertilizer, the soil condition becomes more mellow and loose. As a result, they can plow the soil more easily, compared to soil without added organic fertilizer. The soil supports many living organisms that leave many soil holes that can improve soil aeration. Under natural conditions, earthworms do their activities to plough the soil and increase soil organic matter in the process. As such, costly tillage using machinery can be partly replaced by earthworm tillage. Burrows of earthworms augment water penetration and enhance soil exposure to air. Tunneling can increase the rate of water seepage into the ground 4–10 times higher than fields that lack worm tunnels (Edwards and Bohlen 1996). Earthworms normally flourish where there is no tillage—the lesser and shallower the tillage, the better, because the population of earthworms can be reduced by as much as 90% by deep and frequent tillage (Anon 1997). Earthworms are also sensitive to small amounts of pesticides. Carbamate insecticides including Furadan, Sevin, and Temik are shown to be lethal to earthworms (Edwards and

Bohlen 1996). Farmers also opined that rice pest and insects decreased as a result of organic fertilizer use with plants becoming more resistant against insects and diseases.

13.3.4 Correlations Between Farmers' Attitudes and Their Personal Traits

According to Table 13.1, correlation coefficients (*r*) showed that the educational level of farmers is significantly correlated to their attitudes at the 5% level, indicating that farmers who have higher education tend to have a positive attitude and possess more knowledge about various kinds of organic fertilizers to improve their soil quality. The more educated respondents placed higher priority on environment issues, namely that the environment was at least as vital as the economy. The Grain for Green Project was considered successful and a significantly higher level of support for the project was expressed by the better-educated respondents ($p < 0.05$) (Cao et al. 2009).

Moreover, in this research, extension worker contact of farmers is significantly correlated to their attitudes at the 5% level, meaning that farmers who received more organic fertilizer information through soil extension workers gained more organic fertilizer knowledge to improve rice quality and quantity. Naturally, extension service access can significantly influence the intensity of adoption of different components of conservation farming technology at the 1% level (Mazvimavi and Twomlow 2009). Moreover, extension service played a significant role in improved adoption of maize variety. Further variables such as farm size, credit, area, and farm group membership, which were expected to influence adoption and fertilizer use were not significant (at 10% or lower probability levels) in explaining adoption decisions. Similarly, extension service was vital in making available information illustrating the basics of fertilizer utilization (Ouma et al. 2002).

The age of farmers is significantly correlated to attitudes of farmers at the 5% level, implying that farmers at different ages are likely to have different attitude levels towards organic fertilizer. In this study younger farmers tend to adopt organic fertilizer knowledge towards actual use more than those who are older. Besides, the farmers who operate organic farms are younger with higher levels of education than their non-organic complements. It is presumed that this unique group of organic farmers possesses different attitudes and outlooks towards managing farm production. They act positively and more willingly and are able to expand their farm business doing so in a different manner than their non-organic complements (Lobley et al. 2009).

Furthermore, the professionals who had higher education and were younger in age, had better organic knowledge, maintained positive views on environmental friendliness and were more likely to exploit the organic farming advantage. Professionals' opinions in organic farming showed that knowledge and experience played a positively important role in the formation of their agricultural attitudes. It may denote that increasing organic agriculture adoption becomes widespread; hence, this may encourage other farmers to adopt organic farming in the future (Wheeler 2008).

13.3.5 Farmers' Constraints Regarding Using Organic Fertilizer

The big number of farmers (95%) surveyed always complained that chemical fertilizers were very expensive and involved high investment cost. Among the farmers surveyed, about 84 could not access credit facilities. This is due to the fact that credit facilities cannot be accessed by the poor and small household rice farmers because they do not have previous credit history that can be used to gain access to loans from both agricultural and commercial banks. Farmers also said that the main obstacles to credit access were the high interest charges from the monetary union. Another obstacle is the lack of knowledge about the accessibility of credit and loan. The other constraints cited were lack of knowledge and experience about organic fertilizer (63%), little contact with soil extension worker (58%), the high cost of the transportation (55%), growth of seed weed in manure (52%), and increasing frequency of insects and pests (49%).

13.4 Conclusions

According to the field survey conducted in Surin province, this study showed that rice farmers expressed favorable and positive attitudes towards organic fertilizer for use in their rice farms with most of them applying organic fertilizers derived from their livestock such as cow, buffalo, elephant, and so on. Moreover, the statistical results illustrated that farmers' education, age, extension service contact were correlated to their opinion in organic fertilizer utilization, implying that the farmers who had higher educational levels, had more contact with soil extension workers and services, were younger, were more likely to have a positive attitude and agreed to use and apply organic fertilizer for improving their rice farms. One of the major obstacles in using organic fertilizer is that the farmers could not easily access the credit facilities of commercial and agricultural banks. To support these disadvantaged small household rice farmers, the government should provide low interest loans and collateral security. The establishment of group cooperatives is an alternative for the farmers to help solve their financial problems. Another obstacle is the lack of knowledge and experience in organic fertilizer use. Both extension workers and agencies are the major exponents in transferring new technology and knowledge leading towards a greater adoption of organic fertilizers. The farmers should also participate more actively in training programs and information campaigns regarding the benefit of organic fertilizers. Sound and practical agricultural policy is also very vital for encouraging organic fertilizer utilization in Surin province leading to the overall improvement of the quality of life for small rice farmers living in the region.

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Chapter 14
Imitating Nature to Enrich Waste with New Values and Use It as a New Resource

Clara Ceppa

Abstract On one hand, we are observing a continuous and irrational exploitation of raw materials. On the other hand, we are producing more waste. We should not expect, therefore, that the Earth produces more. We should do more with what the Earth produces, and need to adopt sustainable waste management. We must turn to nature, where there is no waste and where any surpluses are metabolized by the system itself. If we adopt such principles in all forms of production, it will favor the development of zero-emissions production, as the waste (output) of one process is usable as a resource (input) for another production process. Specifically, the research, conducted in collaboration with the Neosidea Group, proposes an analytical tool for configuring and setting up networks among different companies. Industries are led to organize themselves into sustainable local networks, i.e., local production systems where the waste products of one industry can be sold as a resource to another to their mutual benefit. Waste enriched with new values becomes a resource and is made available for producing new products strictly connected to the local know-how. By applying the systemic approach we can see how the cultural identity of the territory is reinforced, the biodiversity is conserved, and the quality of the products generated is improved: this creates positive effects on the territory both in environmental and economic terms.

Keywords Output–Input • System • Connections • Resources • Waste

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14.1 Introduction

Capitalistic development based on the indiscriminate exploitation of resources in the conviction that there is an unlimited availability at zero cost has been the cause of the onset and progressive worsening of environmental problems. In the past 50 years, mankind has changed ecosystems more rapidly and extensively than in any other period of human history to meet the rapid growth in demand for food, water, and timber (Angela and Pinna 2008). In the name of a drive to increase production, we are consuming the world and stressing the Earth.

After the introduction of pesticides and chemicals fertilizers into agriculture, soils have become altered and impoverished to the point that they have either declined their productivity or become decertified because their bacterial microflora has been killed off. This microflora serves the natural task of keeping the terrain fertile and alive. If we consider that earth is the source of life, we must not allow it to die of ill treatment. It is, therefore, necessary to reestablish a balanced relationship between nature and humans based on the respect and value of the land. In other words we need to make a transition from violence against nature to the rational use of nature as soon as possible. The increasingly massive introduction of chemical elements has rapidly compromised other fundamental resources as well, like water and air, from which we obtain most of the indispensable substances for human survival.

Faced with the proliferation of algae, the thickening and expansion of urban smog, and the emanation of odors from rivers, we must acknowledge that clean water and air are not free resources but have an economic and environmental value; this is in contrast with conventional economic theory which saw them as free assets for mankind (Ceppa et al. 2008). It is easy to understand how errors, abuses, the squandering and overuse of natural resources have led to degradation of the various systems resulting in severe damage to human and environmental health. As Janet Abramovitz of the Worldwatch Institute points out: “Many ecosystems have been worn out to the extent that they have lost their capacity to recover and are no longer able to withstand natural turbulence.” Hence we are more vulnerable to “unnatural disasters,” those which have become more frequent and severe because of human activity.” Even though, on one hand, we are witnessing the continuous squandering of the natural resources, on the other hand we are producing more waste. Although in daily life we make an effort to eliminate solid urban waste by differentiated collection, we are paying less attention to industrial and agricultural waste. The latter is perceived as being far from our personal sphere, though the mass media remind us of the growing importance of its impact and the proportions of the phenomena. And this does affect our daily life (Ceppa et al. 2008). We must wake up to the fact that the growing mass of waste generated by agricultural activities is becoming increasingly critical in as much as it causes serious damage to human health and the environment. Humans have recognized the problem too late and have tried to solve it after the life cycle of the product. These actions later proved to be inefficient. The main reason for this phenomenon is that we have always thought of production processes as a sequence of actions, independent from one another, implemented to produce a commodity. However, a huge amount of waste is produced along with these commodities. The waste is considered an obvious result, along with the finished product, of the manufacturing process. And as such it is accepted. In an increasingly complex world, like the one we live in today and which we will inhabit in the future, we must look at the whole production process and see it in its entirety, i.e., not by single phases. We must deal with everything produced, products and waste, and start implementing targeted actions to achieve a substantial harmonization of the relationship between the environment and local communities.

14.2 Focus on the Current Agricultural Context

The economy is made up of various sectors which have different impacts on the environment.

Farming is the first sector studied in the environmental sustainability assessment. Farming has gradually acquired industrial methods over the past 50–80 years, and this has radically changed the natural state of the countryside. In the 1920s machinery began to replace human and animal exertion in activities such as preparing the soil, planting, and hoeing. In the 1930s new allochthonous varieties with a high yield started to supplant the traditional varieties and needed external contributions such as irrigation, pesticides, and fertilization. The use of these methods became increasingly intensive, and the damage they caused became as widespread as it was severe. In the 1960s this development of mechanized methods also spread to developing countries in a process called the "green revolution" (Eldredge 1998). This progressive step considerably increased soil productivity. While at the beginning of the twentieth century (1900), 1 ha cultivated with wheat produced 10–12 quintals a year, today the same hectare produces on average 4–5 times more.

All of this did not occur without direct consequences on the environment and it was mainly through the adoption of pesticides, fertilizers, and intensive farming techniques that had a major impact on the soil, ruined the balance of ecosystems, and increased health hazards for humans and animals.

Modern industrial agriculture often involves improper farming practices, such as the overuse of chemicals. The consequences of imprudent use can kill the bacterial microflora that keeps the soil alive and fertile and reduce future production capacity. This has also compromised the drinkability of numerous watercourses and caused a significant deterioration of the ecosystems in the vicinity of river deltas. Pesticides are usually nonselective and kill both parasites and useful organisms; they can also create new problems, because in the long run parasites develop a resistance to them which compels farmers to use a new compound to fight the same parasite. In so doing, the farmers increase their dependence on these products in a process referred to as a "pesticide mill." Another consequence of introducing elements extraneous to the natural system into modern agriculture is obviously the jeopardizing of the genuineness and wholesomeness of the products that reach our tables and make up our daily diets. Modern agricultural and forestry science is also responsible for the loss of biodiversity because, to guarantee a significant production of varieties that have a high commercial value, it has simplified and homogenized nature; the intensification of a few crops with high commercial value has led rapidly to the elimination of various life forms, impoverishment of the soil, and the destruction of Earth's life support systems (Deb 2004).

Healthy soil depends on biodiversity and consequently better agricultural products: bacteria, algae, fungi, worms, and a host of invertebrates that live in the soil help to recycle and redistribute nutrients. They aerate the soil, maintain the nutrients in proximity to the surface, moderate the water flow, and as a result they increase productivity. Cultivating a field with one, two or at most three plant species requires clearing the land, i.e., cutting down trees, removing bushes, and original grasses. It requires preventing them from regrowing while only the desired varieties are encouraged to grow. The original plants try to reoccupy the land and are considered "infestants", intruders into what was once their territory: in these cases humans have declared war on the local system. Agriculture is a source of food for all humans, but it has had to take on the tones, features, and parameters of classic industry. This has turned it into a lifeless entity. The sundry book *Fatal Harvest* (Kimbrell 2002) provides statistics on the decline of biodiversity in the United States: "between 1902 and 1983: 80.6% of tomato varieties became extinct; 92.8% of lettuce varieties, 86.2% of apples, 90.8% of corn and 96.1% of sweet corn. Of the more than 5000 existing varieties of potatoes, only four make up the overwhelming majority of those cultivated for commercial purposes in the United States. Two types of peas occupy 96% of American crops and six types of corn, 71% of the total." The race to reduce biodiversity is so continuous and unstoppable that it has become imperative to make a change aimed at deindustrializing agriculture and recovering a fruitful relationship between humans and nature. We must come to terms with the fact that the real need today is not to increase production but to reclaim and improve it. Therefore the intensive methods for growing crops and raising livestock must be abolished. Farmers and ranchers work with nature, which is the place of life; therefore it makes no sense for them to deplete it or, worse, to annihilate it by treating it in ways that shocks it. Intensive livestock farming has also contributed to the degradation of the rural environment because, besides having caused the extinction of optimal animal breeds, they leave on the soil manure full of antibiotics and substances contained in the feed but not assimilated by the animal. Other negative effects of agriculture and industry on the environment are caused by the enormous quantity of residues released annually, the elimination of which is not only costly but harmful to health. In all types of activity, whether agricultural or industrial, some of the resources used are returned to the environment in a random and disorderly manner in the form of gaseous or liquid effluent.

This problem has taken on increasing importance in the past few years for several reasons (Santoprete et al. 1996):

- An increase in waste
- The qualitative evolution of waste products during the transition from an agrarian society to an industrial one, resulting in the production of substances that are difficult to eliminate

- The energy crisis
- The impoverishment of primary resources which require recovery
- Ineffective recovery operations

Faced with the incapacity to introduce new methods, we are still using landfills, which should nonetheless be considered a transitory and temporary solution until we can use technologies apt for recovering the various types of elements contained in the refuse. To deal with this problem properly and solve it optimally, we must analyze it from a different perspective that will highlight how our current production activities throw away most of the resources they take from nature. When we extract cellulose from wood to make paper, we cut down entire forests to use only 20–25% of the trees while the remaining 70–80% is discarded as waste (Capra 2004). As Pauli maintains, the time has come for us to stop expecting the land to produce more and to start expecting humans to do more with what the land produces (Pauli 1996).

In the past few years the concomitance of the energy problem with the need to save nonrenewable resources and an increased sensitivity towards environmental protection has led to the spread of a new philosophy, one which favors the production and use of goods that raises the status of so-called waste products to materials worthy of proper, rational, and targeted management to lighten the polluting load and allow direct or indirect recovery of the recyclable and energy elements.

14.3 Waste, Enriched with New Values, Can Be Used as a New Resource

In our era it is precisely environmental degradation, the lack of resources, and the myth of unlimited development that are making us rethink the modus operandi of the various production sectors. The current setup of production is called "linear" because the process is a sequence of independent phases unconnected to each other and the raw materials mainly come from third-world countries.

The focus of production is mainly on the "product" and not on the "process": this setup prevents a vision of the production process in its entirety and consequently hides the possible connections there may be between the phases within a given process or between two different production processes. The critical point of the current linear setup that I would like to examine here is this: waste is created during the various phases of the process and at the end of the life cycle of the finished product. This incurs a cost to the environment but also economic and social costs to the entire community. By adopting the systemic methodology, according to which the outputs of one production process become the inputs (resources) of another, it becomes possible to propose a new production setup, appropriately called "systemic," that can metabolize all types of waste. This becomes possible when we apply to the production sectors those principles that have always regulated the most perfect of systems: nature. In nature there is no such thing as waste and even surpluses are metabolized by the system itself. Designers who use the systemic approach (Bistagnino 2009) see in nature a model and a guide, and their modus operandi is to start by studying the designs and flows of the natural world and to try to incorporate the principles underlying its design and production methodologies. Systemic design questions the current industrial setup which focuses on profit and quantity; it does not focus exclusively on the product (Bistagnino 2008) and the product's life cycle but extends attention, and therefore competence, to the entity of relationships generated by the production process. In this way we are able to learn from the efficiency of natural processes, their complexity, and the necessity for relationships within nature's system. From the point of view of sustainability, the ”projects” and “technologies” of nature are far better than human ones because they were created and have been continuously perfected throughout billions of years of evolution during which the members of the terrestrial family have prospered and diversified without ever consuming resources and services of the planet's ecosystems. The well-being of all living creatures depends on these ecosystems.

This new systemic understanding of life, its organizational models, and basic processes, shows how it is the constant flow of energy and matter through a network of chemical reactions which allows a living organism to generate, repair, and perpetuate itself. The first law of ecology stated by Barry Commoner establishes that: “each thing is connected to all other things.” This truth takes on scientific dignity with the adoption of the ecosystem, introduced by the English ecologist A. G. Tansley (Lovelock 1979) who defined it as follows: “A system in the physical sense, which includes not only the whole of organisms but also the whole of physical factors that form what we call the habitat of living organisms, i.e., environmental factors in the broadest sense.” Planet Earth as a whole can be interpreted as one large ecosystem that is not isolated but open, and receives solar energy, the primary source of life for all living beings (Filippone 2001). This is the principle of autopoiesis, i.e., the capacity of all living beings to generate, maintain, and perpetuate themselves by transforming energy and matter originating from the outside. When Lucretius (Barbero et al. June 2008) wrestled with this fundamental node of Epicurean physics, he came to affirm the eternity of primordial matter which is the seed of all things (*semina rerum*), thus anticipating insights that would rise to the status of law only many centuries later: “Nothing is created and nothing is destroyed.” The balance that regulates the cycles of the biosphere's fundamental elements has always respected that law, continuously recycling the residues of the natural processes until it extracts living matter from it. Therefore nature does not have a notion of waste; only a notion of matter that transforms itself: what is useless to one member becomes food for another; only humans, considering the real presence of intelligence on the Earth, produce things that no one wants. It is time to change direction: like ecosystems in nature, a sustainable human community must use energy from the sun and must not consume any material resource without also recycling it after use; in other words, we must not use any new material.

In order to build sustainable farming societies, we need to help producers organize themselves into ecological groups so that the waste products of a given process can be sold as resources to another process, thereby benefitting everyone. This is the only way we can have a society based on the life cycle of products that is consistent with environmental needs and able to respond to human needs while consuming fewer resources (Lanzavecchia 2000). We need to make a leap in quality from our recent past when, in the name of a presumed right of dominion over nature, we perpetrated downright violence against it which resulted in an enormous waste of precious and often unrecoverable resources. This leap should prefigure a rational control of nature through a growing understanding of its balance mechanisms and the development of a production and consumption organization that respects those mechanisms as much as possible. The transition from violence against nature to a rational use of nature implies and presupposes a similar transition from a society in which certain people are dominated to a society of freedom and equality.

14.4 Creating New Connections by Using the Systemic Software

Our current industries throw away most of the resources they take from nature: to manufacture paper, entire forests are cut down to use only 20–25% of the trees (Capra 2004), while all the rest of the resource is thrown away as waste. To restrain this phenomenon we need to create an instrument for making the changes needed on the level of the management, organization, and procurement of energy and resources. We can start by seeing the importance of creating an IT instrument for study and analysis based on the concept of an open-loop system that can help neighboring companies, according to their business purpose or geographical location, to organize themselves into "ecological networks" to achieve production that moves towards zero emissions by means of sustainable management and the valorization of waste. Moreover, profits can be obtained from the sale of these outputs (waste). This would create new flows of material that would connect different companies.

These enterprises could mutually benefit by allowing the reutilization of the materials expelled from their production processes. The constant exchange of information and sharing of knowledge between the players involved allows a continuous systemic culture to spread, along with the concepts of prevention and the ongoing improvement of the environment. In such a system the flows of materials generate internal links and relationships through single local systems can be defined. These systems would connect the various systems on a regional level and ultimately on a global one. Underlying these concepts we find the fundamental ways to procure resources in an ecosystem: the production of material in loco by using energy obtained from the surrounding environment and the importation of material produced and released by other ecosystems (Chelazzi 2004). The starting point is to consider that the waste from these production processes, currently thrown away and not valorized, abound in precious resources for other manufacturing activities.

The method for holistic assessments allows us to understand all the elements of the complex system of the analyzed setting; in the preliminary phase, the flows of material and energy needed for the proper functioning of a farming or industrial process are evidenced. Then the flows are assessed to determine the connections created between the various operators in the community examined. In particular the flows can be generated by the raw materials for production, by the outputs of a process destined to new uses, or from the energy that is indispensable for each activity.

By using a holistic survey we can generate an exhaustive picture of the area being studied and acted upon and show the internal and external relationships of the system and its connection to the local area. According to systemic methodology, production systems are observed according to their internal and external relations (with related industries), for the purpose of energy use, emissions control, the procurement and transportation of material, and the management of outputs on the territorial level (Barbero et al. 2008). They are redefined during planning and design and the outcome is a complex, ramified, multipolar, and strongly territory-linked operation. In these cases the waste is transformed into a productive resource and new relations arise between local companies, thereby minimizing the use of external resources and allowing greater clarity in terms of the traceability of the production chains. This also helps determine which local activities can be related in an open-loop production system and what types of outputs can be reutilized by other production categories.

To provide a detailed picture of the community being studied, it is vital to quantify the amounts of waste material produced each year in the sectors of agriculture, aquaculture, horticulture, and forestry. As an example, let us use a region of Italy as a reference (Piedmont) where the agro-industrial sector, along with metallurgy and textiles, represent the major production activities of the region. In this context we can see that currently approximately 142,000 t of the waste (Ceppa 2008) produced per year by agriculture, aquaculture, horticulture, forestry, food industry, is used as fuel or brought to the landfill or destined to biological-physical-chemical treatments for the purpose of producing compost or mixtures to be eliminated by scattering them on the soil or storing them in permanent warehouses (Fig. 14.1). These practices not only prevent exploiting the intrinsic wealth of these materials optimally but also cause a notable squandering of resources that can be used in other types of production. Moreover it is important to note that they also cause potential environmental hazards.

In specific terms, we propose the definition, design, and realization of a system, the Systemic Software, for processing information based on evolved technological systems that can acquire, catalog, and organize information relative to the productive activities in the area of study, the outputs produced and the inputs required as resources; these data are acquired and organized in terms of quantity, type, quality, and geographical location on the territory. All the data are correlated with each other by means of a complex logic. The logic and the algorithms that intervene on the acquired information serve to normalize the structures, allowing them to be interlaced and evaluated by evolved technological instruments which serve to render the information in an intelligible and intuitive format for all of those who interface with the Systemic Software (Fig. 14.2).

The consultation of the system was designed by following the systemic approach and made usable by means of Web 2.0 technologies; this approach has made it possible to publish an interactive Web portal as a facility that can be used by operators

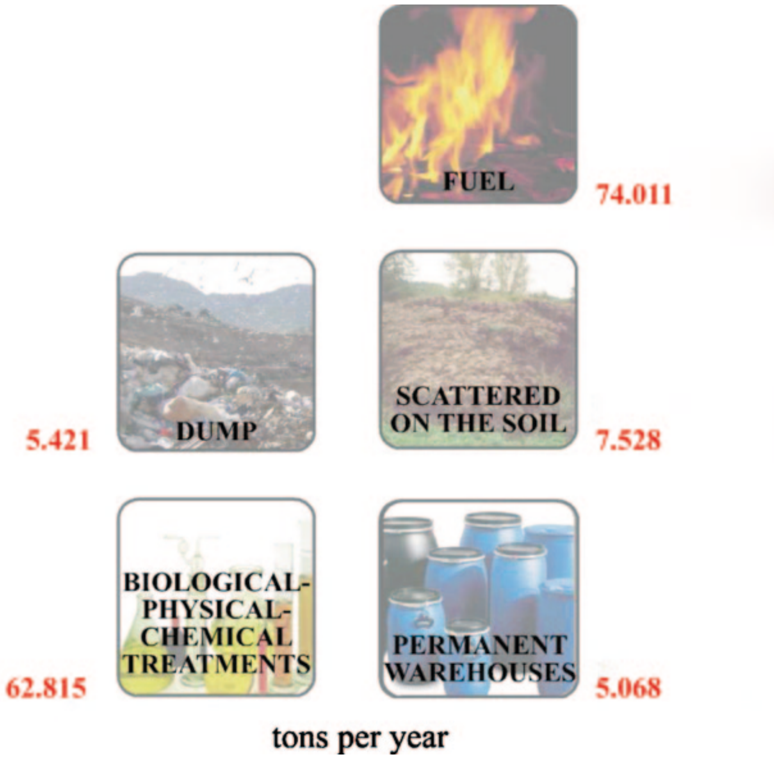

Fig. 14.1 Typology of actual treatment activities of waste produced per year by agriculture, aquaculture, horticulture, forestry and food industry

who want to consult it and interact with it. We start from the premise that the availability of new raw materials must definitely be measured according to type, quantity, and quality; but it is essential to also evaluate their geographic location. This is the added value that Systemic Software offers companies and the community in which they are located. The processing system, developed in collaboration with the Neosidea Group, was also supplemented with the function of geolocating business and materials. This provides a solution and gives not only information regarding new areas of application of the outputs, but also determines with precision and localizes by territory the flows of material within a local network whose nodes are represented by local companies. By using the geolocation function, the system can ascertain which local activities are situated within the range of action (e.g., 60 km or 100 km) defined according to the search criteria. Then it positions them exactly on a geographical map to show the user which companies can be part of the network of enterprises in order to increase their own business and maximize their earnings through the sale of their outputs and the acquisition of raw materials from other local production activities. Thanks to the development of a structured implementation logic based on the systemic vision, the information processing instrument or

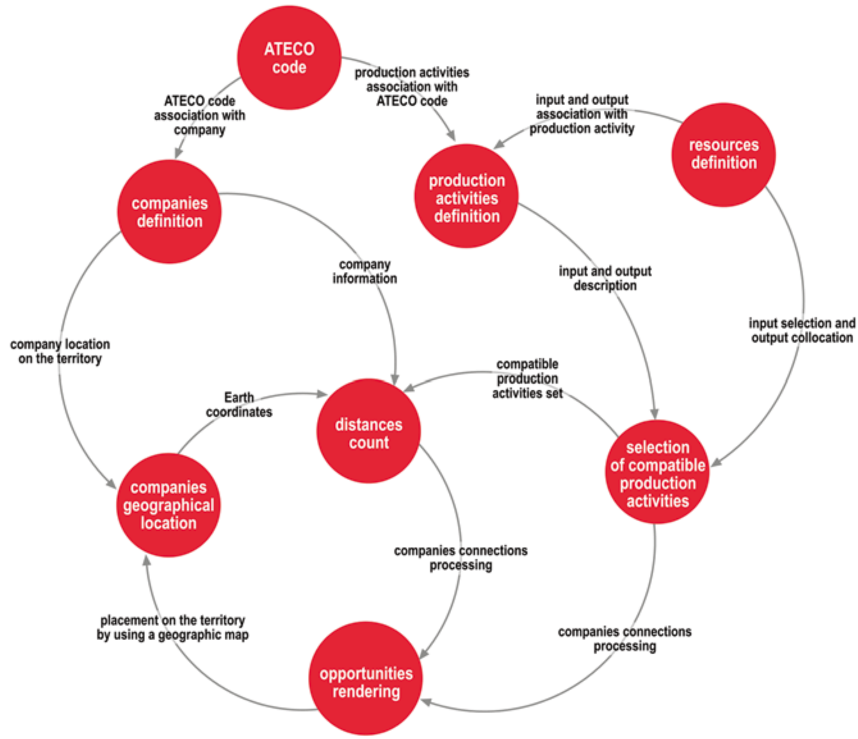

Fig. 14.2 Flow chart of software architecture

Systemic Software is able to provide further information to set up new production chains and new flows of materials and services in favor of all the businesses who join the initiative thanks to a constant updating and comparison among the systemic logics for reusing materials, local productive activities, and the territory itself (Fig. 14.3).

The functions of the Systemic Software are fourfold:

- Producers of waste would be able to determine which local companies could use their outputs as resources in their production process.
- It tells input-seekers which companies produce outputs they can use as resources.
- It informs different producers about new business opportunities on the local territory that have previously remained hidden.
- It is an efficacious instrument for evaluating the entire production process and becomes a tool for providing feedback.

Therefore this system can give useful and reliable information regarding your firm's current production process: if you enter the type of waste produced by your company as a search criterion, and the software gives no results for possible reutilization of your outputs, this means your current production process produces waste that

Fig. 14.3 Example of graph: geographical placement of the activities (*circle green*), situated within the established range of action, which could sell their output to the searching company (*circle blue*)

cannot be reused or recycled. It means your company produces items by using inputs and processes that do not comply with the vision of an open system. Therefore we have observed the need to implement certain changes within the production line, for example to reassess current inputs and substitute them with others that are more environmentally sustainable.

Essentially we are proposing an IT network at the service of the environment. The huge amount of data obtained by using Systemic Software is a precious asset and a vital platform for scholars of the environment, researchers, ecologists, public agencies, local administrators, and, obviously, for entrepreneurs, who will be able to work in a more sustainable way. The advantages of such an instrument are that they: improve usability, facilitate use and satisfaction, expand the potential area of users, improve the use of technological resources and local resources, raise the quality of life of society whose health depends on the way it relates to the environment hosting it, valorize the potentialities of the local territory and of the economy itself. The proposal of a technological support of this type arose from the consideration that this "virtual" web allows us to react more rapidly when confronted with environmental issues, involve different areas of users, and have a positive influence on decisions and actions taken by public institutions as well as on producer companies. It is an indispensable instrument for gaining a thorough knowledge of one's own territory, discovering, and valorizing its potentialities by sharing the knowledge of different people and entities as well as enabling all of the actors involved to cooperate actively.

Production Chain Analysis: Fruit Growing and Processing The availability of new resources urges research that fits the territory analyzed. By viewing the entire production chain from a systemic perspective, it is possible to completely reuse the

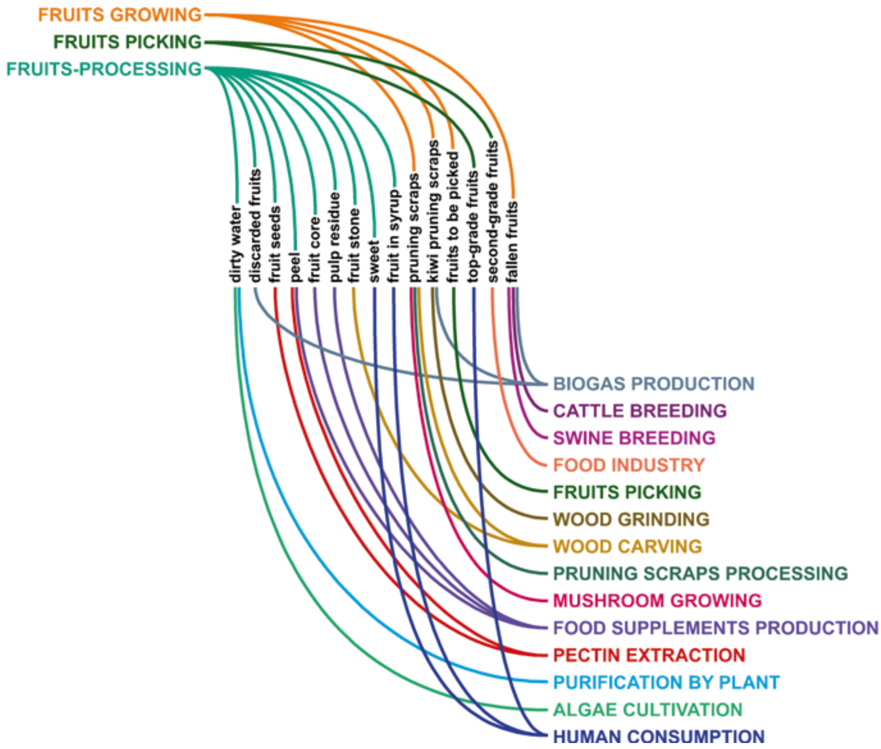

Fig. 14.4 New flows of material generated by using the Systemic Software

waste products that, after being enhanced with new values, become resources. In fact pruning residues are ground and completely reutilized: part is used to create the substrate used for growing mushrooms for human consumption or put in animal feed (e.g., for cattle). The wood can also be used to make pellets. Another part becomes sawdust and the remainder is put into a biodigestor to produce biogas (Figs. 14.4 and 14.5).

The windfall fruit, till today not gathered and exploited, is used to feed livestock (e.g., cattle). The outputs of the food processing industry are totally reused in other processes. Discarded fruit is also sent to the biodigestor, while the pulp, as well as the peeling and coring scraps, are used for the production of energy and supplement bars (food supplements) for human consumption, and meal and pulp for swine and cattle feed. The used water is sent to be purified naturally by plants and used to cultivate algae for human and animal consumption. Moreover, the output of the skin and seed removal phase can be used to extract a percentage of pectin, a precious organic compound in foods, pharmaceuticals, and cosmetics. All this was possible because the outputs were considered raw materials that are full of potential: this allows the so-called scrap to become material worthy of proper, rational, and targeted management for being reused as raw materials for other production processes.

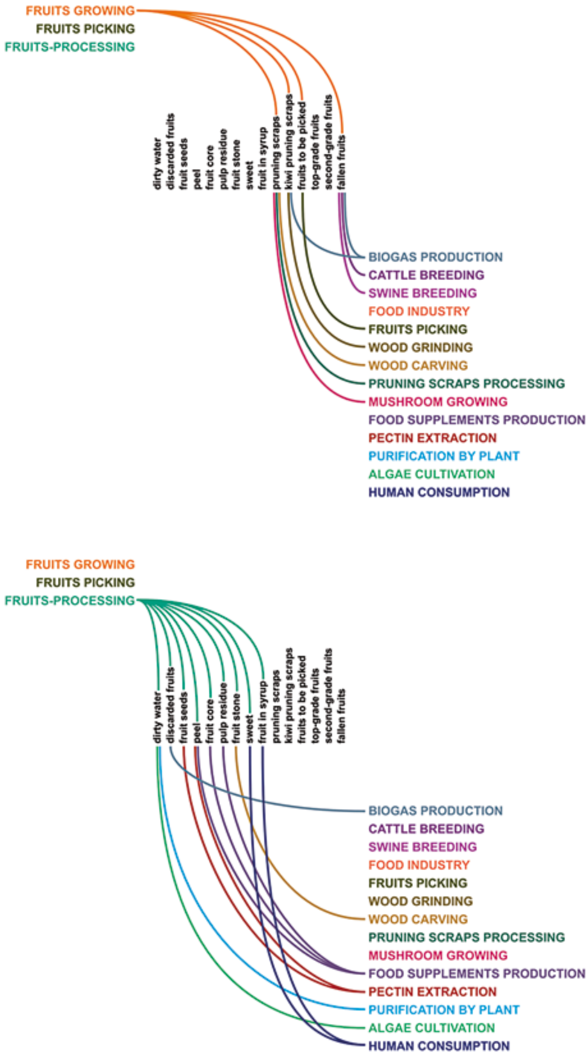

Fig. 14.5 User can choose a specific productive phase

14.5 Conclusion

In conclusion, the software was designed to implement the methodology. If, in fact, the systemic design methodology can transform a cost into a benefit, a waste product into a resource, then Systemic Software could be an instrument that can support the analysis of the system approach applied to a local area and define possible interactions which could lead the creation of a network of companies that can exchange resources and competencies with consequent gain for all involved. One of the greatest "local" benefits of the systemic tool is that it turns the local territory into a scenario for a whole of material and energy relationships, production systems that are self-sufficient in terms of energy, production, and procurement and are closely linked to local skills and know-how. Determining new uses for the outputs that still exist locally reinforces the link between local companies, increases their earnings, and results in a new and significant impact on the local community.

Moreover, the induced links between companies minimize the use of external resources, allow more clarity on the traceability of the industries involved and help determine strategies for potential additional tools for local development. Finding new uses for the outputs was made possible thanks to the study processes that involved not only the products but also the production cycles. These operations have allowed the development of a tool that can automatically generate new connections between the various local production activities. The proposal for a technological instrument of this type also makes it easier for the various community actors to understand, on different levels of complexity, the numerous possibilities offered by systemic culture but particularly Systems Design applied to a productive area. Therefore, the research aims to render knowledge about the systemic-designed instruments of the above mentioned approach and make it more accessible. The combination of this knowledge and technological support instruments improves an understanding of the environmental and the economic benefits generated by a systemic nonlinear territorial productive culture which enables us to transform waste into materials worthy of a proper rational use.

Such an approach is aimed at an optimal management of the waste/materials. More importantly it aims at the profitable reutilization of these materials. This reinforces the concept that effective environmental protection is not in conflict with the economic growth of enterprises. The contribution of systemic methodology to the valorization and protection of any given territory is therefore fundamental. In fact, it creates the context for a set of links between energy and materials, productive systems that are self-sufficient in terms of energy, production, and procurement. All this has close connections to local expertise and skills which can correspond to the human need for well-being based on the rhythms of natural cycles. In conclusion, by decisively relaunching the local economy and improving the ecological condition of the environment in which it is located, Systemic Software is a tool for spreading a powerful and crucial knowledge developed to defend biodiversity, increase business, foster entrepreneurial potential, and optimize production activities with the utmost respect for the greatest resource we all share: Nature.

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Part IV
Recent Innovative Processes in Livestock Production

Chapter 15
Farm Animal Breeding—The Implications of Existing and New Technologies

Joyce D'Silva and Peter Stevenson

Abstract For centuries, humans have bred animals for a variety of purposes. Farm animals have been selectively bred for maximum productivity. However, research shows that many types of farm animals, including poultry, are now suffering ill-health and poor levels of welfare due to these high levels of productivity. High-yielding dairy cows and fast-growing meat chickens are all affected. These animals can no longer survive to a natural lifespan. Such breeds are unsuited to farming in developing countries and more robust and native breeds should be used. Methods such as cloning, which is likely to be used to replicate large numbers of these same high-yielding animals and which may involve wastage of life and considerable animal suffering in its development stages, should be avoided.

Keywords Animal Welfare • Cloning • Health • Productivity • Selective Breeding

15.1 Introduction

For centuries, humans have intentionally bred animals for their beauty (Arabian horses, rare poultry breeds), their usefulness (draft equines and oxen), and for their productivity. Over the last half century or so, selective breeding of farm animals for productivity parameters has become the norm in the developed world and is spreading rapidly to all countries.

At first sight, there is no doubt that a cow producing 11,000 l of milk a year will be more profitable in the short term than a cow producing only 5,000 l, or that a meat chicken getting to slaughter weight in 5 weeks seems economically far more viable than one that takes 12 weeks to reach the same weight. In fact, the industrial model of livestock farming is built on the backs of such highly productive animals.

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However, a closer look at what has been achieved raises serious concerns over the health, welfare, longevity and, because they are so prone to health problems, the economic viability of these fast-track animals. In addition, new technologies such as genetic modification and cloning put yet more power in the hands of the breeding companies and possibly less choice in the hands of the farmer.

15.2 Chickens Reared for Meat (Broilers)

Globally, most of the chickens reared for meat are based on breeding stock produced by just three major breeding companies. The scientific evidence shows clearly that the way commercial broiler chickens and parent stock are bred inflicts serious health and welfare problems on the birds. Genetic selection for faster growth rate leads to painful leg disorders and heart failure in birds reared for meat and to severe food restriction and hunger in the breeding birds.

Over the second half of the twentieth century the growth rate of commercially produced broilers has been increased greatly, with standard broilers now reaching 1.5 kg body weight in 30 days whereas 120 days were needed in the 1950s. In a 2010 scientific opinion, the European Food Safety Authority (EFSA) stated that this marked increase in growth rate is largely the result of genetic selection. It stresses that "it is generally accepted that most of the welfare problems [of broilers] are caused by genetic factors" (EFSA 2010).

EFSA concluded that "the major welfare concerns for broilers are leg problems, contact dermatitis, especially footpad dermatitis, ascites and sudden death syndrome. These concerns have been exacerbated by genetic selection for fast growth and increased food conversion" (EFSA 2010). The opinion points out that there is an increased mortality associated with faster growth rates whereas slower growth rates have a lower mortality.

At present, a high proportion of broilers have serious leg disorders and these are a major cause of poor welfare. There are serious welfare concerns about skeletal disorders in broilers that lead to lameness and this is measured by examining the birds' gait. The gait scoring system developed by scientists from the University of Bristol assesses birds' walking ability (0 = normal, 5 = unable to walk). High gait scores (3 or more) indicate a marked inability to walk normally and these abnormal gaits have been associated with fast growth rates and pain.

A recent large-scale study into leg disorders in broilers concluded that "the primary risk factors associated with impaired locomotion and poor leg health are those specifically associated with rate of growth" (Knowles et al. 2008). In this study, the authors assessed the walking ability of 51,000 broilers from 176 commercial flocks (n = 4.8 million) belonging to five major UK producers and quantified the risk factors for poor locomotion in broilers. They found that on average 27.6% had a gait score of 3 or higher, i.e. lameness that is likely to be painful and that a major risk factor was bird genotype. The study reported that 43.5% of the chickens had gait score 2 and the EFSA opinion points out that "although a few birds may have a non-painful structural abnormality, the most likely cause of 'a definite and identifiable defect in gait (score 2)' in a broiler chicken is some localised pain or lesion".

The figure of 27.6% of broilers having gait scores of 3 or more is broadly similar to a Danish study that found 31.1% to have gait scores of 3 or more (Sanotra et al. 2001) and a Swedish study that found 20.4% to have such scores (Sanotra and Berg 2003).

Selection for rapid growth and feed conversion efficiency is therefore clearly one of the main causes of poor health and welfare in commercial broiler birds. A comprehensive review of broiler welfare (Bessei 2006) concludes that slower-growing breeds have fewer leg problems, fewer incidents of metabolic diseases, and lower mortality levels than birds bred for fast growth.

A number of scientific studies have shown that compared with fast-growing chickens, slow-growing chickens have lower lameness levels (Bassler et al. 2005), less severe lameness problems (McNamee and Smyth 2000), and fewer associated problems such as cartilage deformation, an occurrence of 1.2% compared with 47.5% in fast-growing birds (Havenstein et al. 1994).

Broiler breeding companies are still aiming to reduce the number of days it takes the chickens to reach slaughter weight, as this means farmers can produce more chickens per year. A previous report from scientific experts in the European Union supported the view that the broiler breeding companies could undoubtedly improve the welfare of broilers by selecting for improved leg strength and walking ability and by reversing the trend towards faster growth rates (SCAHAW 2000). But the trend to faster growth rates continues.

Ascites and sudden death syndrome (SDS) are two important lethal diseases of broilers that are both metabolic in origin. Ascites is a result of dilatation and hypertrophy of the right side of the heart which leads to cardiac failure and changes in liver function causing accumulation of fluid in the abdominal cavity. SDS affects mainly fast-growing male birds.

A genetic predisposition exists for both ascites and SDS and there is a link between growth rate and ascites and probably also SDS. Fast growth rates increase the risk of these two diseases by increasing oxygen demand which puts pressure on the cardio-pulmonary system. As growth rate and oxygen demand coincide with other physiological challenges, this may lead to cardiac failure. Some slow-growing genotypes are more resistant to ascites; mortality caused by ascites is higher in fast-growing broilers than in slow-growing birds.

The recent EFSA opinion (EFSA 2010) recommends that there should be a strategic objective that the broiler industry places a high priority, say over the next 10 years, to decreasing the proportion of birds with the higher gait scores in commercial flocks in order that lameness is minimized, even if this objective may require them to reduce growth rate. Major improvements in welfare could be achieved both for birds reared for the table and breeding birds by using strains with the genetic potential for a growth rate of no more on average than 45 g live weight gain per day.

Whereas backyard chickens, often of strong native breed, can walk, run and even fly up into trees to perch, these fast-growing birds are no longer able to fly or run and spend most of their time squatting on the floor, where the litter material can become wet or sticky if not managed well. This reduced locomotion can lead to leg weakness and contact dermatitis, a widespread problem in broiler production. In severe cases, the erosions develop into painful ulcerations. It is a sad reflection on industrial farming that lying down is now the main behaviour for fast-growing broiler chickens.

It does seem ethically unacceptable to intentionally breed chickens that grow so fast that they are highly likely to suffer painful conditions like lameness and appear predisposed to a range of sometimes fatal health conditions.

15.3 Pigs

Modern pig breeding has also led to a reliance on animals selectively bred for fast and meaty growth. Here again we see that the breeding strategies themselves are causing health and welfare problems for the animals.

In 2007, EFSA published a scientific opinion on fattening pigs and concluded that "Leg disorders, which are caused by a complex of factors including genetic selection [for rapid growth and lean meat] and ad libitum feeding of high energy and high protein diet, are a major problem in fattening pigs. These cause poor welfare because of pain, reduced ability to move around and increased risk of victimisation" (EFSA 2007).

They went on to say that the genetic selection of pigs for rapid growth and lean meat without enough consideration of other factors has led to some widespread and serious problems, in particular leg disorders, cardiovascular malfunction when high levels of activity are needed or stressful conditions are encountered, and inadequate maternal behaviour (EFSA 2007).

There are many welfare problems encountered in industrial pig farms, such as close confinement of pregnant sows in narrow stalls, keeping pigs on barren slatted floors and routine painful mutilations such as castration and tail-docking. But the actual breeding of pigs for productivity parameters also has a major adverse impact on their health.

15.4 Dairy Cows

In the developed world, more and more dairy farmers have come to use the high-yielding Holstein breed of cow, either pure-bred or an animal with significant amounts of Holstein in her genetic make-up. Holstein cows have long, lean bodies and can produce astonishing amounts of milk. In fact, the highest yielding cows now produce probably 10 times more milk than their calf would have suckled from them. The calf is usually removed from the mother at a day old, so that she can be milked to capacity for human consumption of her milk.

These cows have doubled milk yields from 30 years ago and can now produce 50 l a day, which equates to 10,000 l a year. Such cows are programmed to produce these vast amounts of milk, but to do so they have huge needs for high-energy food. Grass alone cannot provide them with sufficient nutrients. In order to sustain their high yields, they are often fed cereals and soy feed mixes along with forages like silage (fermented grass). The soy may be imported and its production may be associated with destruction of the rain forest or other precious ecosystems.

Research shows that diets that are rich in cereals can have an adverse impact on bovine health. High-concentrate (cereal rich) feed is inappropriate for ruminant animals whose digestive systems are designed for fibrous food, such as grass and silage. Feeding a large proportion of concentrate feed can lead to transient acidosis of the ruminal environment (EFSA 2009). Recurrent acidosis may eventually lead to ruminitis and abscesses in the liver and other tissues. Moreover, sub-acute ruminal acidosis has been linked to other signs of poor animal welfare such as loss of body condition, laminitis, and high herd culling rates (EFSA 2009).

These cows are often kept in poor quality indoor systems, such as concrete cubicles, for much of the year. They may lack comfortable bedding and suffer from high rates of lameness, up to 25% of cows at any one time in the herd (Whay et al. 2003). They are prone to mastitis, a painful inflammation of the udder, associated with high levels of milk yield. They struggle constantly to balance their need for rest with their need to eat to satisfy their nutritional requirements. Eating so much means that they often feel full up, yet are simultaneously compelled to continue eating. This is a horrendous dilemma which we have imposed on these animals. If insufficient food is available, the cows quickly become emaciated. One of the main reasons for culling cows at such an early age—after just two or three lactations—is her failure to come into oestrus and conceive. This is a symptom of her exhausted metabolism.

A major review of the scientific literature by EFSA concluded that "Long term genetic selection for high milk yield is the major factor causing poor welfare, in particular health problems, in dairy cows" (EFSA 2009).

15.5 New Breeding Technologies

Selective breeding involves breeding only from those animals who display the characteristics which the breeding company or farmer wishes to propagate in future generations. Although selective breeding can be used to propagate robust animals or slower-growing chickens, too often decisions are made solely on the criterion of profitability. So animals continue to be bred for fast growth, high productivity, and yield, often with disastrous consequences for their health and welfare.

As global recognition of the sentience of animals becomes increasingly accepted, it is likely that such breeding strategies will become ethically unacceptable to most people. Already the European Union countries have formally recognized animals as "sentient beings" in the Treaty of Lisbon[1] (European Union 2010) and many countries are establishing new laws to protect the welfare of animals, including farm animals.

However, even as more and more people worldwide are becoming sensitive to the welfare of farm animals, biotechnology companies are carrying out research into cloning and genetic engineering of animals for food.

Genetic engineering of farm animals, often with added growth hormone genes, has resulted in the birth of some appallingly deformed creatures and has not really reached the farm gate. However genetically modified fish, such as salmon, have already been developed and there are widespread concerns that they may escape from fish farms and pollute the genes of wild salmon.

[1] The Treaty of Lisbon was signed on 13 December 2007 in Lisbon and entered into force on 1 December 2009.

The technology that is beckoning at the door is cloning. The aim of cloning is to produce genetically identical copies of an animal. Like genetic engineering, cloning is a wasteful technology, as most cloned embryos do not make it to the foetal stage. Although cloning can be used to replicate a GM animal, and is likely to be used in this manner in the future, right now cloning is likely to be used primarily for replicating the highest yielding cows and pigs. Of course, it is these very animals that have been badly affected by being bred for high levels of productivity. Now we have a technology which can take an infinite number of cells from a high yielding cow, clone them in the laboratory and implant them into low value "surrogate mother" cows.

This is an invasive process. In pigs, the transfer of the embryo into the surrogate mother is performed by a surgical procedure. In cattle, embryo transfer is sufficiently stressful for UK law to require a general or epidural anaesthetic. Many other countries have no such rules. Scientific research shows cloning often involves severe suffering both for the surrogate mothers and for the clones themselves.

Cloned calves tend to be heavier than normal which leads to painful births for the surrogate mothers and as a result Caesarean sections are often needed. Surgery is always stressful for the animal.

Most clones die during pregnancy and of those born alive, a significant number die early in life. For example, up to 35% of cloned calves die during or shortly after birth or in the early weeks of life from a range of problems including heart failure, respiratory difficulties, muscle and joint problems, and defective immune systems (EGE 2008). These animals have short lives of suffering.

EFSA has said that "The health and welfare of a significant proportion of clones have been found to be adversely affected, often severely and with a fatal outcome" (EFSA 2008).

In view of these problems, the European Commission requested an opinion from its ethical advisory body, the European Group on Ethics (EGE) in Science and New Technologies. This group of eminent ethicists concluded that "considering the current level of suffering and health problems of surrogate dams and animal clones, the EGE has doubts as to whether cloning animals for food supply is ethically justified". The EGE added that it "does not see convincing arguments to justify the production of food from clones and their offspring" (EGE 2008).

The industrial farming industry claims that it really intends to use the successful clones for breeding and use their offspring for meat or milk production. Those concerned with animal health and welfare, like the advocacy group Compassion in World Farming, say that the technology is rooted in animal suffering, that it is unnecessary, unwanted by the public and not the way forward for sustainable farming.

Cloning and genetic engineering of farm animals is taking us in the wrong direction—towards perpetuating factory farming when all other society trends point towards sustainable farming and respect for animals as sentient beings. Cloning animals for food is therefore both an ethical issue and a sustainability issue.

Cloning is an inefficient way of feeding the growing world population. Clones and other high yielding animals are fed on cereals. Cereals and soy make up around 80% of the feed given to intensively reared animals.

15.6 Conclusion

Future farming in both developed and developing countries would be unwise to rely on animals selectively bred or cloned for fast growth and unsustainable levels of productivity. High yielding animals appear to be more vulnerable to infection, have shortened longevity potential, and require high levels of cereal and soy feeds to maintain their production levels.

Feeding cereals and soy to animals is inefficient as much of their food energy value is lost during conversion from plant to animal matter. Research shows that several kilos of cereals are needed to produce 1 kg of edible meat. Using cereals and soy as animal feed is a wasteful use not just of these crops but also of the increasingly scarce resources of land, water, and fossil fuel energy used to grow them.

Up to 20 kg of cereals have to be fed to intensively reared cattle to produce 1 kg of edible beef. These crops could feed more people if they were used for direct human consumption rather than being fed to animals. The most efficient way of rearing cattle is to let them graze at pasture eating grasses and having their food supplemented as far as possible with "left-overs" such as straw rather than with human-edible cereals and soy. This way they are converting something we cannot consume, grass, into meat and milk that we can eat.

The great strength of extensively reared cattle and sheep is both that they convert grasses into food that we can eat and that they are able to use land that is generally not suitable for other forms of food production. The great inefficiency of intensively reared cattle, pigs, and poultry is that they consume grains that humans could eat directly.

High yielding Western breeds often prove to be unproductive in developing countries. Having been developed in North America and Europe, such breeds are often unable to cope with the endemic infectious diseases common in the warmer climates of much of the developing world and are less hardy than native breeds. The International Livestock Research Institute (ILRI) has warned of the dangers of replacing traditional low-input breeds of animal in developing countries by higher yielding breeds imported from industrial countries. High-yielding farm animals are usually developed for use in temperate climates, whereas native breeds in developing countries are adapted to cope with the local conditions of heat, drought, disease, and parasites (such as ticks) and lower quality feed. These conditions can increase the risks of production failure in animal breeds that are not well adapted to survive them.

ILRI gave an example of Ugandan farmers who had switched from indigenous Ankole cattle to higher-yielding Western cows, then lost nearly all the cows during a drought when the animals were not robust enough to walk long distances to water (FAO 2007; Kinver 2007). Studies in South Africa have shown that cattle from imported Western breeds lose 15% of their weight when they have no water for 24 h, whereas the weight of local cattle is hardly affected (Hoffmann 2008).

The World Bank has recognised that industrial scale livestock production risks undermining rural livelihoods in developing countries, as smallholders cannot compete with the economies of scale enjoyed by large producers (World Bank 2001).

When large industrial farms are introduced into a rural area, nearby small-scale farmers often cannot compete and are driven out of business and off the land. In short, industrial livestock production robs many small farmers of the opportunity to provide food for themselves and their families and to earn additional income by selling produce to markets and nearby urban areas.

Industrial livestock production can also facilitate the development of animal diseases. Intensive livestock production methods, where large numbers of animals are kept together in a confined space, greatly increase the potential for infections to be spread between animals. In addition, intensive livestock production provides conditions that facilitate the development of more virulent pathogens. Intensive farms provide pathogens with a large number of hosts in close proximity and conditions in which different strains of pathogen can co-infect one host and facilitate genetic mutation and recombination (Greger 2010).

A report by the Food and Agriculture Organisation of the United Nations and others, "Industrial Livestock Production and Global Health Risks", points out that industrial livestock production plays an important part in the emergence of highly pathogenic avian influenza and other diseases (Otte et al. 2007).

The US Council for Agricultural Science and Technology has warned that a major consequence of modern industrial livestock production systems is that they potentially allow the rapid selection and amplification of pathogens (CAST 2005).

Industrially produced meat is of lower nutritional value than meat produced extensively. There is growing evidence that grass-fed beef and lamb have greater nutritional value than intensively produced meat. Animals fed on grass have higher levels of Omega-3 in the meat than those on a grain-based diet. Omega-3 fatty acids are important for healthy brain function and prevention of heart disease.

For all these reasons, the authors believe that selectively breeding or cloning animals to propagate fast growth rates or high yields is a grave mistake and that the resulting animals will prove of fleeting benefit to the most industrialised farmers in developed countries and will prove possibly catastrophic for farmers in developing countries.

Sustainable livestock farming has a future, but that future depends on using robust breeds of animals, adapted to local conditions and who can live lives of quality in high-welfare farms.

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Chapter 16
Animal Husbandry in Focus of Sustainability

András Nábrádi, Hajnalka Madai and Adrián Nagy

Abstract The question of the sustainability of agricultural production, considering especially the animal production sector and its development, can be dated back to the second part of the twentieth century. Sustainability is a subject of priority today, as sustainability is considered to be a core element influencing our existence and in the survival of forthcoming generations. The notion of sustainability comprises three aspects: ecological, social and political and economic target systems, which by now have been supplemented with cultural and regional elements, including the protection of the environment, local traditions and the scale of values, cultural and historical heritage. The principles of sustainable development also include the improvement of human and animal health and the maintenance of vital rural communities. For centuries, sheep have contributed substantially to grassland-based agricultural production in Hungary. The sheep sector supports rural areas as a tool for sustainability in the animal production sector. This paper briefly reviews the levels of sustainability in Hungarian animal production, focusing particularly on sheep production. We then identify the most significant economic issues affecting this sustainability through use of a "SWOT" analysis, a "problem tree" and "structure of objectives" methods, based on our findings.

Keywords Animal production • Objective and problem trees • Sustainability

16.1 Theoretical Background and Methodology of Sustainability

Today, sustainable agriculture and livestock production encompass three main goals: environmental (ecological) health, economic profitability and socio-political equity. Local areas have failed to receive that much attention, although certain tasks

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such as sustainable agriculture or regions are much more likely to be solved on local (national) levels. Csete and Láng (2005) asserted that the sustainable development of the agro-economy can be effectual within the system of content, tasks and levels of the whole economy. Geographically scattered, different size agricultural producers play a significant role by introducing sustainable farming systems and by operating sustainable enterprises, while also providing new opportunities for exploiting regional and national levels. Utilizing livestock in agriculture often improves the sustainability of the system of an environmental (ecological), economic, and social viewpoint. Animal production can be economically sustainable because of its role in trade, market and feed supply disruptions, as it diversifies the activities of producers, decreases controls risk at the farm and national levels, enhances farm maintenance and increases the possibilities for employing the rural population. However, in a globalised and highly regulated economy, it is a more complex problem. The economic aspect depends on the two other aspects and especially the attitude of people and politics. The evaluation of sustainability is also based on the level of examination: local, regional or national.

In 2007, the Department of Agricultural Economics and Rural Development, Centre of Agricultural Sciences and Engineering, University of Debrecen organized a series of workshops entitled "Generation of projects based on sector-specific innovation in various sectors of animal production". The program was supported by the National Office for Research and Technology (NKTH) and the North-Great Plain Regional Development Agency (ÉARFÜ), within the framework of the Gábor Baross tender dossier. The participants of the events were requested to provide their ideas concerning the conference lectures and to give proposals in relation to the problems of the sector. In all the issues related to the industry (improvement, variety, foraging, technology, processing, trade, animal health, sectoral control, watchdogs, economics), renowned experts were invited to give lectures and to introduce discussions. The event was interactive, as after certain vertical blocks of lectures, participants were able to give their comments and ask questions. All the conference participants were asked to prepare a written memorandum on the advantages, weaknesses, potentials and threats of the sector and to send these to the organisers. Based on this material, we prepared a SWOT analysis and a problem tree of the sectors, as well as a structure of objectives which might lead to the solutions to the identified problems. Here we introduce the results regarding the sheep sector.

We did not revise what was mentioned and written down in these memoranda (we neither supplemented them nor subtracted anything from them). In our opinion, we were not allowed to do so, as all the sectoral players have a good understanding of their own areas of expertise. Rather, we have strived to systematize what was said and written down at the conference. Below, we present and evaluate the focal economic issues of sustainable animal production, and especially sheep production, on the basis of this work. As the first step of the relationship between cause and effect we considered weaknesses and threats. On the strength of these findings, we prepared a so-called problem tree, showing elements in logical relation with each other. To eliminate the problems, we outlined a so-called system of objectives.

Weaknesses and Threats, the Problem Tree The weaknesses and threats pertaining to the sheep sector were logically grouped. Human factors, production, consumption, processing, trade, capital supply, animal health and factors affecting the environment are included separately.

Weaknesses If we consider sectoral problems, it can be seen that these have many elements in common and several similar weaknesses. In the sheep sector, where forages are consumed, the lack of sectoral strategies was highlighted. "Hunger" for cutting-edge knowledge, low capacities for pushing their interests, low social prestige and the lack of experts and producers supporting them and their causes were mentioned. In the production sector, high forage prices and cost levels were mentioned. Naturally, in accordance with the characteristics of technical sectors, specialities also emerged: e.g. the size of plants, indicators of progeny, slurry and forage supply. In the problem areas of consumption and processing, non-competitive processing structures, product improvement and the lack of innovation, inflexibility were shed light on. In the sheep sector, low national consumption, the lack of processing capacities and the low level of processing were mentioned. In the category of capital supply, for the sheep sector, the opinion was that there is a lack of capital. It means that producers even have not got the needful equity ratio to make supports of use or prefinance their production or development. A characteristic problem of capital for fodder users is that in ownership conditions the forage area, livestock and stables are separated from each other. In landscape protection areas, producers of sheep pointed out existing anomalies.

Threats In the analysis of the threats, it seems apparent that the number of human factors has reduced as compared to threats. If the existing system prevails for long, threats will include the contradiction between the ageing labour force and the simultaneous problem of the group of small-scale producers, which is practically dying out, which can further harm the prestige of animal production. The danger that the new political interests may outweigh agricultural experts has also emerged. The spreading of bureaucracy and its unnecessary expansion can tie up the energy and time of producers and processors. In the production sector, in the case of forage users, the characteristic danger of fodder price rises can already be foreseen in relation to bioethanol and biodiesel production. In parallel, income losses due to the prospective increase of energy prices and labour costs can be identified across the board. In the area of sheep and lamb meat consumption and processing, no direct threats were detected, while several sources of threats have been identified in the commercial sector (e.g. live animal transport, labelling). The apparent threats seen in the sudden advance of international competitors, which endangers the survival of those with weak market bargaining power, combined with the enhancement of asymmetric successes of interests dictated by trade and the survival of the black market, all impair the position of the sector and enhance the fear that Hungary may become a net importer in several sectors. As regards animal health and the environment, all sectors of animal production face several threats. These include diseases, epidemics, inland water and flood dangers, environmental restrictions and extra expenses in relation to climatic changes.

The Problem Tree If we build the categories of weaknesses and threats on to each other in a logical process, we receive a so-called sectoral problem tree. The complexity of the figures shows that several causes lead to the above-mentioned serious situations, namely to competitive weaknesses, to increased national and international defencelessness, to social-societal, economic, environmental, sectoral and market problems. The logically connected elements of the problem tree show the relations of cause and effect from bottom to top.

The Problem Tree of Sheep Production The problem tree of sheep farming shows that the resultant problems are focused into a single, serious block of effects. This block has been given the title "*a sector reacting with difficulty to economic, social and environmental changes and challenges*". This indicates that there is not merely one means available for solving the relation of causes and effects and sometimes only multiple approaches can yield results (Nábrádi et al. 2007), (Fig. 16.1). The lower part of the problem tree lists the problems, which are the same as in the previous trees. If we recall the definition of sustainability, we can see that the sector is actually not stable from this aspect either. This instability is related to cause and effect which further weakens the competitiveness of Hungarian sheep farming; its added value and innovation are low level, and the branch will therefore be unsustainable in the long run. For all these reasons, the region cannot retain its population, enterprises are liquidated, the landscape is being transformed; production and commerce become unviable. Social and societal problems are reflected in the fact that the sector is losing its prestige as the production section is ageing; however, provincial unemployment, which cannot be converted into other areas, is soaring. Economic-environmental problems are due to the fact that the capital attraction potentials of the available sectors are low and, as a result of unexploited and neglected grasslands, the costs of landscape maintenance and health care increase. A direct consequence of the liquidation of enterprises is the deterioration of the quality of life. Sectoral-market problems are manifested in the fact that, due to an unfavourable variety structure, yields are low, market defencelessness can further increase and the lack of import, low concentration and producer cooperation can render the sector non-competitive from the outset. To our understanding, the example presented means that the logical system of relations in the problem tree built on the SWOT analysis can be well applied for the investigation of sustainability and for the exploration of cause and effect relations.

Structure of Objectives, Hierarchy of Targets In animal and sheep production, one of the most outstanding and significant areas of agriculture, our objective is to increase productivity, job creation, job preservation and added value, to improve competitiveness and simultaneously to rationalize the use of resources. The strategic objectives of the sector can be summarized in one sentence, as follows: to achieve competitive production in Hungary again. To realize this goal, specific objectives should be worked out, under which we can subordinate concrete, expected results, which can be achieved by the simultaneous performance of a set of activities. Figure 16.2 brings together the comprehensive sectoral objectives, expected results and the factors describing realizable activities in the so-called structure of objectives.

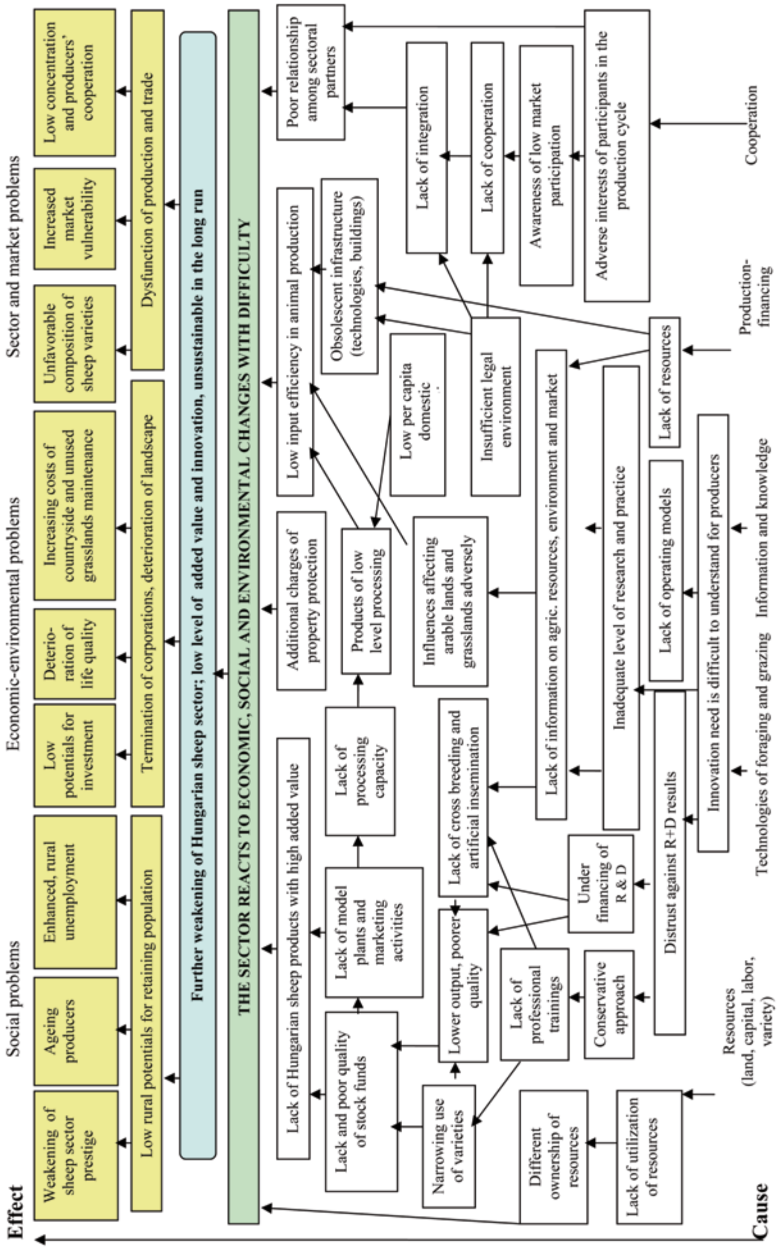

Fig. 16.1 Problem tree of the sheep sector

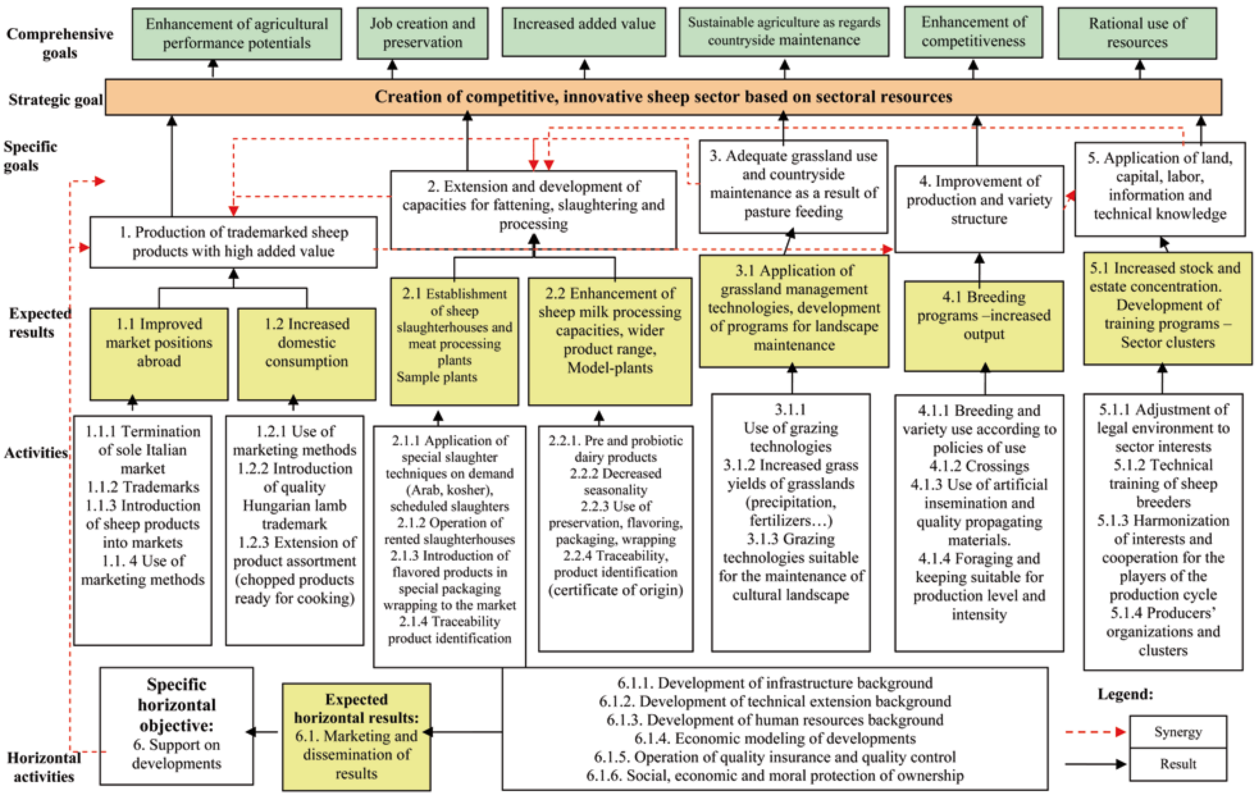

Fig. 16.2 Objectives' tree of the sheep sector

The layers build on each other in the system of the problem tree; therefore, we modified the tree to reveal the relations of cause and effect in such a way that the factors causing disadvantageous situations can be terminated. As may be seen, the structure of objectives displays five well definable specific features (from top to bottom): comprehensive objectives, strategic objectives, specific objectives, expected results and activities. Our comprehensive objective is the one directly above the concrete target, while our results are objectives linked to the concrete target from the bottom, towards the realization of which we devised concrete activities. From among these, we highlight several economically significant issues.

16.2 Evaluation of Sheep Production from the Point of View of Sustainability

In the system of the structure and hierarchy of objectives, it must be stressed that certain elements of potentials and their realization can improve the situation of a producer or trader separately. However, it should be noted that, in the case of the entire sector of sheep farming, only complex measures can lead to sound effects. There is another extremely important element, which is true not only of sheep farming, but of the animal production sector. Responsibility for policies for the development of the strategic, operational and support systems of the sector cannot be easily fitted into the system of the hierarchy of objectives. On the table of the structure of objectives in sheep farming, a special element of activities appears which is collectively called a horizontal activity (then result, specific target built onto it). The word “horizontal” denotes that it is related to all activities. If we have a look at this figure, it shows the background developments for infrastructure, extension and human resources necessary to realize these activities. If we survey the first system of objectives, the following logical series can be determined: By applying marketing methods, introducing sheep products into markets, using trade marking, terminating the single Italian market, our foreign market position can improve. In this manner, in addition to being then able to simultaneously increase domestic consumption, the production of trademarked sheep products with high added value would be made possible, while Hungary would find itself in a position to promote the creation of competitive and innovative sheep farming.

Sheep, milk, wool and their resulting products, the production of breeding animals and the production and marketing of reproductive materials can be focal points among the objectives of the cluster. In the interest of the future, hard work is needed now, as the successful solution of problems requires adequate political or social background and sectoral climate. The organization of the sheep sector cluster or clusters has been started by the University of Debrecen.

Our hypothesis, which claims that, as things stand, sustainable animal production with a variety of factors and animal breeding enterprises cannot be maintained, has been proved. The reasons behind the negative tendencies are complex, and can only be disclosed by including the entire industry’s sectoral players. There are significant factors of sustainability such as the contribution by animal agriculture of greenhouse gas emissions and the consideration of animal welfare. Due to the dramatic fall in the number of livestock in Hungary, greenhouse gas emissions decreased by almost 50% at the beginning of the 1990s and stagnated in the period between 1995 and 2002. According to the latest data, gas emissions from ruminant animal production constitute only 1,8% of the country's total emissions (HCSO 2006). Due to the small sheep population in Hungary, at the regional level, greenhouse gas emissions are not a significant problem. The situation of animal welfare in the sheep sector has normalized and become balanced. Hungary, and especially Hungarian agriculture, applies all the rules and directives of the European Union. All the instructions of Cross Compliance for animal sectors are in process. In the case of the sheep industry, the main problem is live lamb and sheep transportation, which is a traditional trade practice between Hungary and some European countries. By applying the proper marking and transportation rules, problems may be minimised in this field. Other approaches are also harmonised in sheep production because of long grazing seasons and partly-housed keeping practice. Presently, we cannot state that the problem of sustainable animal and sheep production has been solved. Rather, we have taken the first steps towards achieving this goal. What is clear and inevitable follows like this:

- The precise and expedient clarification of all the problem spheres relating to the sectors of animal production is reasonable by the inclusion of all the participants of the product cycle in similar structures.
- The starting point of analysis is to disclose the relations between cause and effect.
- By setting up the structure and hierarchy of objectives, activity tasks can be identified.
- All these tasks should be coordinated according to a time schedule and included in a complex system. Then, develop a strategic plan broken down by sector and then for the sector as a whole. If only certain activities are identified and realized, this could pose a range of new threats.
- The triple pillars of sustainability, the fulfilment of environmental, social and economic expectations, can only be realized by setting a strategy.

Although our production and consumption are insignificant when seen globally, the export–import activities of our animal production are measurable in terms of world trade, even if only slightly. On a regional level its impacts are of moderate strength. On the national and local levels, its impacts are distinct and strong. Its relation to and interaction with the countryside, natural resources, nature as a whole, society and economics is weak on the regional, medium and national levels and strong on the local level. The greatest problem in the relationship between sustainability and animal production is presented by the way people think and live. As mentioned previously, this opinion is subjective in nature. From among the major elements of sustainability, purposeful ways of thinking, behaviour and lifestyles matching them are decisive.

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Chapter 17
Effect of Urea-Treated Sorghum Stover Supplemented with Local Protein Sources on the Performance of Sheep

Fithawi Mehari Gebremariam and Goitom Asghedom

Abstract On-farm feeding trials were carried out to examine the effect of supplementing urea-treated sorghum stover (UTSS) with sesame cake (SC) or fishmeal (FM) on the body weight of sheep. Twenty-one male sheep were divided into three groups of seven sheep in each treatment. All the sheep used in this experiment were from breed (Gerej), with the same age and initial body weight and from the same area.

The feeding trials were conducted in Gash Barka situated in western lowlands of Eritrea. Initially all the sheep were fed on UTSS for an adaptation period of 15 days. The control diet consisted of UTSS fed ad libitum, the second and third treatments were composed of UTSS fed ad libitum, supplemented daily with 80 g/head of SC and 60 g/head of FM, respectively. The experiment was conducted for 90 days and both feed intakes and body weights were recorded regularly. The results showed that the dry matter intake (DMI) was significantly different ($p < 0.05$) between the control and SC-supplemented groups, but not between the other treatments. It was the highest for the SC-supplemented group at 847 g/head/day followed by the FM-supplemented group and the control at 826 and 821 g/head/day, respectively. Sheep supplemented with SC had the highest significant ($p < 0.05$) body weight gain (BWG) (134 g/head/day) followed by the group supplemented with FM (115 g/head/day). The BWG for the control was 66 g/head/day. Feed conversion was best on SC (6.92) followed by FM (7.70) supplementation. The lowest cost of feed per kg of BWG (16.91 Nfa) was attained by supplementing with SC. It can be concluded that feeding UTSS alone or supplementing with small amounts of SC or FM can increase the live weight of sheep at a reasonable cost.

Keywords Urea treatment • Fishmeal • Sesame cake • Sorghum stover

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17.1 Introduction

The feed, its adequate and timely supply, and quality are the most important input in livestock production throughout the year. This is an essential pre-requisite for any substantial and sustained expansion in livestock output.

Among the major constraints limiting the potential development of livestock production in Eritrea, inadequate feed has been identified as the crucial bottleneck. In most areas, especially during the dry period, livestock fed only on crop residues or the native pasture cannot even meet their maintenance requirements or they lose body weight. Most ruminants are consequently subjected to chronic undernutrition: they lose weight in the dry season and early wet season, and this makes them more vulnerable to diseases. In order to feed livestock all the year round, excess feed produced during the rainy season must be conserved for the following dry season.

Low quality feeds such as sorghum and barley straws and stalks are staple feeds for ruminant livestock in traditional subsistence farming of Eritrea. Scarr (1987) and Singh et al. (1993) showed that sorghum stover in particular contains far higher proportion of lignin, which reduces its nutritive value and the actual dry matter intake (DMI) and digestibility by cattle and sheep. Thus, most animals which have a basal diet of sorghum stover lose weight, become weak and are more susceptible to diseases during the dry season (Kayouli 2006). These feed sources contain insufficient nitrogen to provide the ammonia needed by rumen micro organisms for the efficient fermentative digestion of such feeds. However, there are appropriate technologies to improve the nutritive value of these residues. Urea treatment and correct supplementation with locally available supplements have been successfully used in many developing countries (Chenost and Kayouli 1997; Dolberg 1992; Hector et al. 1990; Hadjipanayiotou and Economides 1997; Zhang et al. 1995; Singh and Schiere 1993; Ben Salem et al. 1994). Treatment of straws or stover should not be the sole method considered, but supplying with locally available agro-industrial by-products should be pursued. Two such by-products that are available in Eritrea are sesame seed cake and fish meal.

17.1.1 Statement of the Problem and Objectives of the Study

Crop residues from wheat and barley in the highland and sorghum and millet in the lowland of Eritrea are the most important sources of ruminant feed during the dry season. Until the recent times, sorghum stover was not properly collected and stored by the farmers in the lowlands. Rather it was grazed by the ruminant livestock while it was in the field. Nowadays farmers are aware of the importance of stover and they start to collect and store them properly after the harvest season.

The potential nutritive value of straw and stover or low quality forage cannot be exploited if the microbes in the animal's rumen do not receive the correct balance of nutritive elements for its efficient consumption. If one is expecting higher production rates from the animal, the necessary nutrients needed for this must be given through the supply of additional or "supplementary" supplements. These constitute the nitrogenous and energy supplements needed to enable the rumen microbes to function well. The objective of nitrogenous and energy supplements is to ensure additional supply of nutritional elements to the animal to achieve a targeted performance level.

Several positive results based on the supplementation with oilcakes and FM of urea-treated sorghum stover has been achieved in other countries (Preston and Leng 1984; Williams 1984; McDonald et al. 1973; Maglad et al. 1984; Little et al. 1991; Prasad et al. 1993). However, this approach has not yet been studied in Eritrea. As a result, there is no reliable information on the application of supplementation methods to livestock production in Eritrea, in particular to intensive and semi-intensive livestock production. Based on this, the following objectives were set for the present study:

- To examine the effect of feeding urea-treated sorghum stover supplemented with locally available protein sources (fishmeal or sesame cake) on the performance of local sheep.
- To estimate the economic value of the treatments.

17.2 Materials and Methods

This sheep feeding trial was carried out on farm. It was conducted the in Adi-Omer Mixed Farming Project. The research site is located along the banks of the Gash River near the town of Tesenei.

A total of 21 local growing male sheep, 6–7 months of age were kept for 3 months of actual experimental period preceded by 15 days of adaptation. After balancing for initial live weight and age, the sheep were randomly allocated into three treatment groups of seven sheep each. The treatment groups were then randomly allocated to one of the three diets. One group was fed on urea-treated sorghum stover ad libitum (T1). The second and third groups were fed on urea-treated sorghum stover ad libitum supplemented with 80 g of sesame cake (SC) (T2) and 60 g of fishmeal (FM) (T3) per sheep per day on dry matter (DM) basis as shown in Table 17.1. The diets in the two treatments with supplements of SC or FM were formulated to be iso-nitrogenous. The rations in T2 and T3 were thoroughly mixed before they were offered to the sheep. Ear tags were used for the identification of each sheep in each pen.

Table 17.1 Daily diet composition of the three treatments

Species	Treatment 1 (Control)	Treatment 2	Treatment 3
Sheep	UTSS ad lib	UTSS ad lib + 80 g SC	UTSS ad lib + 60 g FM

UTSS Urea-treated sorghum stover, *SC* Sesame cake (g DM), *FM* Fishmeal (g DM)

There was an already constructed sheep house which was made up of doum palm leaves. The house was then partitioned into three parts for the three treatments.

After the 15 days of adaptation, body weights were measured every 15 days of interval before feeding and watering. The DMI of the sheep was arrived at each group by the difference between the weights of feed offered and feed refused every day. Five kilograms of urea were dissolved in 60 l of water and evenly sprinkled onto layers of a 100 kg of chopped sorghum stover. The stover was then stacked into a concrete pit and covered by plastic sheet to maintain an air tight condition for a period of at least 2 weeks. Samples of the diets were collected at regular intervals and analysed in laboratory. The nutritional content was analysed according to standard procedures described by the Association of Official Analytical Chemists (AOAC 1984).

The feeding trial was designed according to a completely randomised design (CRD). Mean live weight gain (LWG) and daily DMI were analysed with GENSTAT Release 12.2 (2003) Windows software.

17.3 Results and Disscussion

Urea treatment of sorghum stover was effective in upgrading the nutritional value, particularly the crude protein (CP) content of straw. The CP content increased by 77.9% from initial 6.25% to final 11.12%. These findings are similar to the results of Saadullah et al. (1981) which show that the CP content of sorghum stover increased from 2.2% to 11.9% when treated with 5% urea. In another study O'Donovan et al. (1997) showed that untreated straws initially having 2–4% CP have a potential CP level of 7–12% after treatment, which was sufficient for the maintenance of live weight (Table 17.2.).

The urea treatment was successful because the treated stover displayed the physical characteristics of successful treatments in the form of a pungent smell of ammonia, the stover was dark brown in colour and no mould growth was observed. The treated stover also became soft enough to be consumed by the sheep, which were only 6–7 months of age. At the time of feeding, the sheep were highly attracted to the treated stover and consumed much of it.

There was a highly significant ($p < 0.001$) difference in weight gain for treatments containing SC or FM compared to the control. The DMI was significantly

Table 17.2 Chemical analysis of the ration ingredients (% of DM)

Feed ingredient	DM (%)	Ash (%) of DM	CP (%) of DM	EE (%) of DM	CF (%) of DM	Energy (MJ/kg)
NTSS	87.00	12.60	6.25	0.72	32.50	9.35
UTSS	60.00	12.70	11.12**	0.88	29.67	9.83
SC	89.81	11.87	44.47	13.93	9.24	16.12
FM	89.87	27.95	59.15	5.44	1.93	12.90

NTSS Non-treated sorghum stover, EE Ether extract

**Estimated value according to Chenost and Kayouli, 1997

($p < 0.05$) different between the control (T1) and SC-supplemented groups (T2), but there was no significant difference ($p > 0.05$) between control and FM-supplemented groups as well as SC and FM. The reason for the increased DMI in the supplemented group could be due to the N added by urea treatment which facilitates the cellulolysis process in the rumen and increases the rate of digestion resulting in increased DMI. Chenost and Kayouli (1997) pointed out that the ultimate objective for adding supplements to low quality forages is to ease their digestive utilization and to increase their intake. This can only be achieved by optimizing the process of cellulolysis in the rumen.

The straw intake and weight gain obtained in the control group of this experiment was higher than that found by others. Hadjipanayiotou et al. (1993) found that the weight gain of Awassi sheep with untreated straw was 73 g/day and increased to 88 g/day with urea treatment, but the straw intake remained constant at 744 g/day. However, from the feed requirement table presented by Jurgens (1997), a 21 kg sheep consumes a total of 1 kg of feed daily, which was similar to the DMI recorded in this experiment (Figs 17.1 and 17.2).

The feed conversion was higher in the SC-supplemented group than the other two treatments (Table 17.3). There has to be a good economic reason for a farmer to feed treated straw or stover and/or to add supplements, and the effects have to be visible. In this study, the cost of feed per kilogram of gain was also the lowest in the SC-supplemented group. The higher cost per kilogram of gain of the FM-sup-

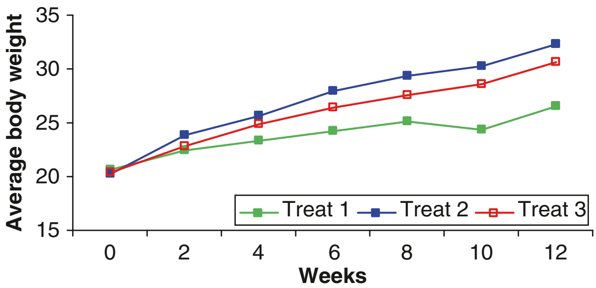

Fig. 17.1 Weekly body weight change (kg) of sheep in the three treatments

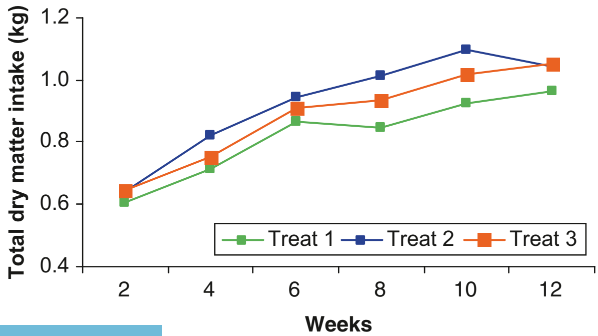

Fig. 17.2 Weekly DMI of sheep in the three treatments

Table 17.3 Mean values for live weight change, feed intake, feed conversion and cost of feed by sheep fed urea-treated sorghum stover supplemented with SC or FM

Parameters	Treatments		
	1	2	3
Number of animals	7	7	7
Initial body weight (kg)	20.643	20.243	20.343
Final body weight (kg)	26.557	32.286	30.671
Experimental period (days)	90	90	90
Daily gain (kg)	0.066[a]	0.134[b]	0.115[c]
Daily total DM intake (kg)	0.821[a]	0.927[b]	0.886[a, b]
– Daily treated sorghum stover intake (kg)	0.821	0.847	0.826
– Daily supplements (FM or SC) intake (kg)	0.000	0.080	0.060
Feed conversion (kg feed/kg gain)	12.439	6.918	7.704
Cost of feed (Nfa/kg gain)	25.72	18.94	25.80

LSD for LWG = 0.01758; LSD for DMI = 0.0833.
[a, b, c] Means in the same row not having common letters differ significantly ($p < 0.05$)

Table 17.4 Cost summary of the treatments of sheep trials

	Sheep: cost summary of each treatment		
	T1	T2	T3
Total cost (Nfa)	2,069.50	2,599.10	2,869.50
TCost (Nfa/head/day)	3.285	4.13	4.55
BWG (g/head/day)	0.066	0.134	0.115
TCost (Nfa/kg gain)	49.77	30.82	39.57

Total number of days = 90
BWG body weight gain, *TCost* total cost, *Nfa* Nakfa (Eritrean currency)

plemented group was due to its higher cost of FM and lower gain obtained. In this study, FM-supplemented diet was found to be more expensive in terms of cost than the one supplemented with SC or urea-treated sorghum stover alone (Table 17.4).

17.3.1 Discussion

There could be different reasons why SC-supplemented groups had higher weight gains than the FM-supplemented groups. The increased total DMI with the SC-supplemented group could be one reason. Lindsay et al. (1982) indicated that the greater weight gain of supplemented animals is due to the increased intake of the basal diet. Another reason for the superiority of SC could be related to its chemical composition compared to that of FM. The FM used in this trial had higher ash, lower ether extract (crude fat) and lower energy contents than the SC. This may affect the DMI, which affects the LWG.

Parsons (2006) and Shah and Muller (1983) shows that meals that contain higher amounts of ash are generally considered to be lower in protein quality and have a lower amino acid digestibility. McDonald et al. (1995) indicated that high ash content is a reason for the low energy content of a feed ingredient.

The higher fat (EE) content of SC, which contains dietary long chain fatty acids (LCFAs), could have contributed to the increased gain of the groups supplemented with SC. Sanderson et al. (2001) reported that FM supplementation increased rates of ash and crude protein gain, but had small effect on fat gain.

17.4 Conclusion and Recommendations

The sheep fed urea-treated sorghum stover in this experiment not only maintained their weight, but also gained an appreciable and economically worthwhile amount of weight.

Inclusion of small amount of SC as supplement in ruminant livestock also had a significant effect in increasing LWG and reducing the cost of feed per unit gain of weight. Therefore, it is concluded that supplementing urea-treated sorghum stover with SC or FM in sheep can have reasonable economic returns in semi-intensive commercial sheep fattening systems.

Based on the present study it is recommended that further research with different levels of SC supplementation is required to determine the most economic level. Because crop residues are bulky, they are difficult to transport economically. It would therefore be more economic worth to treat crop residues in areas where they are found abundantly to fatten sheep and transport the finished ones. Fine chopping of sorghum stover could be helpful, especially for sheep, to reduce the problem of selection in the urea-treated straw. Strong extension linkages have to be developed to popularize urea treatment of straw, particularly in farming systems where wastage of crop residues occurs. Further work on urea treatment has to be done on crop residues of finger millet, maize stover and dried grasses.

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Chapter 18
Evaluation of Spineless Cactus (*Opuntia ficus-indicus*) as an Alternative Feed and Water Source for Animals During Dry Season in Eritrea

Habteab S. Teklehaimanot and J. P. Tritschler

Abstract Throughout East Africa, animal feed resources fluctuate seasonally and are often of limited availability. Finding alternative feed resources that can sustain animal production during the long dry season is an essential need. Cactus is a drought tolerant and succulent feed resource available throughout the year in Eritrea. This study was conducted to evaluate the effect of increasing levels of spineless cactus inclusion in the diet of sheep fed urea-treated barley straw. Twenty-four fat-tailed Highland male sheep with a mean live weight of 21.1 kg were randomly assigned into four treatments (T1–T4). Animals in T1 received ad libitum amount of urea (5%) treated barley straw (UTBS) alone, while those in T2, T3 and T4 received ad libitum UTBS supplemented with 175 g, 350 g and 525 g of spineless cactus (dry matter basis), respectively. With increasing level of cactus, there were significant increases in DMI ($p < 0.001$) and body weight performance ($p < 0.05$), while water consumption decreased ($p < 0.001$). The highest DMI was found in the last two treatments (101.8 and 96.5 g/kgBW$^{0.75}$d, respectively) as compared to the first two treatments (94.4 and 87.6 g/kgBW$^{0.75}$d). The water intake was significantly decreased with the progressive increase in cactus. The highest body weight gain (51.9 g/day) was found when sheep received 350 g dry matter (DM) of cactus (T3), while the lowest was in the control diet (26.8 g/day). The metabolism trial demonstrated that available energy intake was directly related to performance in the feeding trial. In conclusion, feeding cactus with UTBS can significantly increase animal performance and feed intake, and reduced water intake.

Keywords Cactus • Ruminant • Eritrea • Dry season • Intake

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18.1 Introduction

Animal feed and water shortage is one of the main constraints for the livestock sector in arid and semi-arid region of East Africa. The major feed resources come from the rangeland pasture and crop residue. The quality and availability of these feed resources decrease rapidly following the rainy season. This fluctuating pattern of animal feed supply results in a pattern of gain and loss in animal growth and performance. In a country like Eritrea where feed shortage is such a serious problem, utilization of multipurpose trees and shrubs that can cope with low and erratic rainfall, high temperature, poor soils, and required low-energy inputs can serve as an alternative strategy to reduce the chronic animal feed and water shortage. Spineless cactus possesses important characteristics for animal feed in drought-prone regions. This includes high dry matter yields (DM), drought tolerance, nutritive value, and palatability for animals (Tegegne 2001). Spineless cactus (*Opuntia ficus-indica*) is a fast growing xerophytic plant. Cactus has high water use efficiency due to its crassulacean acid metabolism (CAM) photosynthetic pathway. Cacti serve as an extremely important fodder in water-scarce, semi-arid regions (Felker and Inglese 2003). It is well adapted to marginal land with poor soil fertility and the low, erratic rainfall conditions. Cactus remains succulent during the long dry season and can serve the animal as a source of feed and water during this period. Furthermore, cactus is suitable as human food, as fuel, for medicine, as bee forage, and in rangeland rehabilitation projects (Barbera et al. 1995). The aim of this research was to assess the potential of spineless cactus as an alternative source of feed and water for ruminant animals fed poor-quality roughage during the dry season.

18.2 Material and Methods

The experiment was carried out in the highland of Eritrea, which is characterized by a semi-arid climate. A randomized complete block design was used to allocate 24 fat-tailed Highland male sheep with an initial mean live weight of 21.1 kg into one of two replications for four feed treatment groups (T1–T4), consisting of six animals per group. Animals in T1 received ad libitum amount of urea (5% by weight) treated barley straw alone, while those in T2, T3 and T4 received ad libitum urea-treated barley straw supplemented daily with 175 g, 350 g and 525 g of spineless cactus (DM basis), respectively. Diets were offered twice daily, aiming at 20% refusals. At the end of the feeding trial, four sheep were transferred to metabolic crates where digestibility trials were conducted for each diet over 7 days of feeding and collecting. Data were analyzed using standard analysis of variance (ANOVA) and general linear models (GLM) with GENSTAT statistical software.

18.3 Results

18.3.1 The Chemical Composition of Spineless Cactus Cladode

The chemical composition (proximate analysis) of the spineless cactus and urea (5%) treated barley straw is presented in Table 18.1. Spineless cactus cladodes were high in water and ash, but low in crude protein and crude fiber content. In this analysis, cactus had 65% more digestible energy than urea-treated straw.

18.3.2 Effect of Supplementation on Feed Intake

The performance characteristics of sheep fed urea-treated barley straw supplemented with increasing level of spineless cactus is presented in Table 18.2. The amount of cactus in this study was restricted; however, it was a highly palatable feed. Except for T2, there was a highly significant ($p < 0.001$) increase in the total dry matter intake (DMI) with increasing spineless cactus levels in the diet (94.35, 87.57, 101.81 and 96.48 $\mathrm{g/kgBW^{0.75}d}$, for T1, T2, T3 and T4, respectively), and as expected a comparable reduction in straw DMI. The highest DMI expressed on metabolic

Table 18.1 Chemical analysis composition of experimental feed ingredients

Feedstuff	% DM (as-fed)	% CP (DM)	% CF (DM)	% EE (DM)	% NFE (DM)	% Ash (DM)	Energy[a] (MJ/kg DM)
Spineless cactus	12.9	4.7	15.8	0.9	61.6	16.7	13.2
Urea-treated straw	69.4	10.2	46.5	1.1	34.8	7.2	8.0

DM dry matter, *CP* crude protein, *CF* crude fiber, *EE* ether extract, *NFE* nitrogen free extract
[a] Digestible Energy

Table 18.2 Performance of sheep supplemented with increasing level of cactus

Parameters	T1	T2	T3	T4	LSD
Initial body weight (kg)	21.25	21.25	21.08	21.25	NS
Final body weight (kg)	23.67[b]	24.25[b]	25.67[a]	25.50[a]	0.832
Weight gain (g/day)	26.8[b]	33.3[b]	51.9[a]	47.2[a]	12.26
Cactus DMI (g/day)	0	175	350	525	–
Total DMI (g/kg BW0.75d)	94.35[b]	87.57[c]	101.81[a]	96.48[b]	3.418
Water Intake (l/day)	1.98[a]	0.78[b]	0.57[c]	0.18[d]	0.03
DOMI (g)	541.8	504.8	667.8	656.3	–
DCPI (g)	61.2	51.8	61.5	42.6	–
TDNI (g)	542.0	588.2	672.0	663.1	–

LSD Least significance difference, *DOMI* digestible organic matter intake, *DCPI* digestible crude protein intake, *TDNI* total digestible nutrient intake
[a, b, c, d] Means with different superscripts (a–d) in the same row differ significantly ($p < 0.001$)

weight basis (102 g/kgBW$^{0.75}$d) was found in sheep that received 350 g spineless cactus and was highly significant ($p < 0.001$) compare to the other treatments.

18.3.3 Effect of Supplementation on Water Intake

There was a clear trend where animal water consumption was significantly ($p < 0.001$) reduced with increasing intake of cactus (Table 18.2). Sheep in T1 consumed more water (2 l/day) than the other treatments (0.85, 0.51, 0.15 l/day for T2, T3 and T4, respectively). Compared to only urea-treated straw (T1), sheep in T2 drank of 50% less water per kilogram of feed intake. Sheep in T4 approached no water consumption. The trend of water consumption with increasing level of cactus is shown in Fig. 18.1.

18.3.4 Effect of Supplementation on Animal Performance

There was a significant difference in body weight gain in sheep with cactus supplementation to urea-treated-straw-based diets (Table 18.2). The live body weight gain was significantly ($p < 0.05$) higher for sheep on T3 and T4 compared to the control diet (T1). The highest body weight gain (51.9 g/day) was found when sheep received 350 g DM of cactus (T3), while the lowest was in the control T1 diet (26.8 g/day). Even though the total DMI of the sheep in the control was higher than that of the sheep in T2, sheep in the latter group performed better.

18.3.5 Apparent Digestible Nutrient Intake

A digestibility study was conducted, and apparent digestible nutrient intake was determined (Table 18.2). Increasing the level (or proportion) of spineless cactus

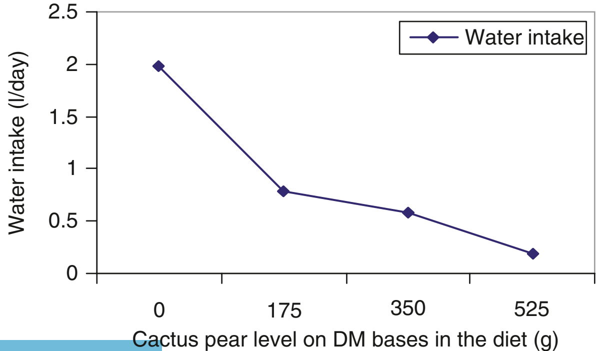

Fig. 18.1 Trend of water intake of sheep with increasing level of spineless cactus

in the diet increased the energy density of the diet. Therefore, supplementation of cactus tended to increase energy intake (total digestible nutrient intake or digestible organic matter intake). In contrast, increasing the level (or proportion) of cactus decreased the CP density in the diet. Thus, supplementation of cactus tended to decrease CP intake. The DCPI was highest on diets T1 and T3, and lowest on diet T4.

18.4 Discussion

18.4.1 The Chemical Composition of Spineless Cactus Cladode

The high water and low CP content of spineless cactus cladodes found in this trial are similar to values reported by other authors (Nefzaoui and Ben Salem 2001; Flachowsky and Yami 1985) for cactus pear grown on poor soils. The protein content of cactus was below the general minimum of 7% CP required for normal microbial activity in the rumen. Therefore, animals fed with cactus-based diets need appropriate source protein supplementations. This study confirms that urea treatment of low-quality forage can be a suitable protein source. In semi-arid regions, where water is a very scarce resource, the high water content can be considered as a benefit. To develop a feeding system using locally available feed resources, an abundant and cheap source of carbohydrate is very important (Preston and Leng 1987). This makes spineless cactus highly valuable for its energy content.

18.4.2 Effect of Supplementation on Feed Intake

Voluntary DMI is related to the intake potential of the feed and the nutrient demand of the animal (Coleman and Moore 2003). Cactus is a highly palatable feedstuff. Higher total DMI in T2 could be associated with the higher consumption and digestibility of cactus. Earlier, Tegegne et al. (2005b) found that total DMI increased for sheep progressively from 77 to 100 g/kgBW$^{0.75}$d when the cactus supplement increases from 0 to 60% in pasture- and hay-based diets. In the current study, the gradual decrease in DMI of urea-treated straw can be explained by the substitutive or associative effect of feed when replaced with a highly soluble source of carbohydrate. In this study, there was not any digestive disturbance or health effect observed even at highest cactus inclusion rate that substitute about 50% of the DMI. Previously, Ben Salem et al. (1996) observed that spineless cactus could be fed without any digestive disturbance up to 55% of the total DMI. This would help farmers to economize their straw budget. The absence of a negative effect coupled with higher digestibility and water content would facilitate a rapid disappearance of cactus from the rumen (Nefzaoui and Ben Salem 2001).

18.4.3 Effect of Supplementation on Water Intake

Water intake was high when sheep were fed urea-treated barley straw alone. However, there was significant decrease in water intake with the progressive increase of cactus. The declining water intake of sheep was in good agreement with pervious works (Tegegne et al. 2005b; Ben Salem et al. 1996), which reported that water intake decreases significantly as the level of cactus intake increased in diets of low-quality roughages. Sheep drank negligible amount of water when the cactus supplementation reached 525 g/day. In line with this finding, Ben Salem et al. (1996) indicated that sheep stopped drinking water when the cactus intake reached 600 g/day. In the tropics, the dry season is characterized by higher temperatures, decreased supply of water, and higher DM of herbage. Therefore, animals that are sustained on poor-quality dry roughages are in need of high amounts of water to facilitate digestion. Animals travel long distances to reach water points, spending more energy and losing body weight. In East Africa, during the drought season the distance traveled to watering points increased by 43–52% for small ruminants (Ndikumana et al. 2002). In countries where water is a vital resource during the dry season, the high water content of cactus could play a significant role in mitigating drinking water shortage. It may also reduce rangeland degradation as animals converge to the water point during the drought.

18.4.4 Effect of Supplementation on Animal Performance

There was a significant difference in body weight gain when urea-treated barley straw was supplemented with spineless cactus. This result was in accordance with pervious works (Tegegne et al. 2005a) on supplementation of cactus to urea–treated-wheat straw-fed sheep. The higher performance of sheep in T3 and T4 as compared to the control (T1) diet can be correlated with associative effects of high total DMI of the sheep in those treatments and the higher readily digestible carbohydrates content of spineless cactus. Even though the total DMI of the sheep in the control (T1) was higher than that of the sheep in T2, sheep in the latter group performed better. This could be attributed to the lack of readily fermentable organic matter for sheep that were fed urea-treated straw alone. The DM digestibility of the urea-treated straw was higher when it is supplemented with cactus than when it was fed alone. Therefore, the value of cactus as a cheap source of energy for efficient utilization of non-protein nitrogen is also important in improving the nutritive value of poor-quality roughage. A 22% body weight improvement was achieved in this study, which is quite interesting as animals lose body weight normally during the dry season, although cactus pear is abundant and succulent in this season. A much higher improvement (72%) in body weight gain was reported when cactus was supplemented with bypass protein source (Shoop et al. 1977).

18.4.5 Apparent Digestible Nutrient Intake

The digestible nutrient intake data of the metabolism trial was in agreement with the feeding trial. Increasing spineless cactus supplement to the urea-treated-straw-based diet resulted in improvement of the energy density of the diet (higher TDN percentage). Body weight gain as a measure of animal performance was highly correlated with DMI and its energy concentration, and these results were consistent with other researchers (Moore et al. 1999). The higher performance of sheep in T3 and T4 as compared to the first two treatments may be explained through increasing the available dietary energy and through an associative effect. In this associative effect, the addition of cactus improves the total digestibility of the diet, including the digestibility of the straw. With increasing level of cactus in the diet, there was an increase in the energy concentration of the diet, while the protein concentration decreased. Besides the slight improvement in performance of sheep in T2, cactus supplementation at the lower level (175 g DM) did not result in a significant difference as compared to the control diet (T1). This might be because, although T2 shows an improvement in energy, there was both a decreased percent dietary protein and lower daily digestible protein intake. In this case, the higher energy may not properly be utilized for better growth, because protein becomes limiting to animal performance.

The crude protein intake of the animals was lower for this group (T2) than either T1 or T3. When the actual crude protein intake was compared to the estimated NRC (1985) requirements (see Table 18.3), these animals may have a lack of adequate protein intake.

At this level, the animals are able to maintain the protein intake, so that they could benefit from the extra energy and optimize growth. Therefore, animals in T3 had a higher TDNI compared to the other groups, illustrating a more optimal balance of protein and energy. Inclusion of cactus at a higher rate (T4) was still better than the first two treatments, indicating benefits from additional energy, but it may have begun to decrease due to low protein intake.

Table 18.3 The crude protein intake (CPI in g/day) of sheep (20–25 kg weight) in the study as compared to the estimated requirement for sheep from NRC (1985)

CPI determined in this study	Treatment	T1	T2	T3	T4
	Observed	97.80	82.79	98.28	68.08
CPI estimated from NRC (1985)	25 g ADG	92.5	92.5	92.5	92.5
	50 g ADG	100.5	100.5	100.5	100.5

ADG average daily gain, *CPI* crude protein intake

18.5 Conclusion

In conclusion, feeding cactus in combination with urea-treated barley straw significantly increased animal performance and feed intake, and significantly reduced water intake.

In this study, it was evident that for diets based on urea-treated straw, the optimal inclusion rate for cactus is about a third of the diet and (or) 350 g/day of cactus DM for sheep. Below this level, cactus reduced the protein content of the diet, so only a slight improvement was seen over urea-treated straw alone. Above this level, cactus could contribute a laxative effect to the diet, so that no further improvement was seen over the 350 g/day level. Therefore, utilization of spineless cactus as animal feed could play a vital role in promoting sustainable livestock production by providing an alternative feed as well as water for animals in dry areas.

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Chapter 19
Comparative Feeding Value of Halophyte as Alternative Animal Feed for Small Ruminants in Eritrea

Kal'ab N. Tesfa and Fithawi Mehari

Abstract Totally 160 sheep and goats were used in 84 feeding trial days to compare the feeding value of halophyte as alternative animal feed with locally available. In this study, three feed types, i.e. halophyte (H), sorghum husk (SH) and *shishay* (S)—locally manufactured commercial feed—were used to formulate the ration of the four treatments (i.e. Tr. 1 Tr. 2 Tr. 3 and Tr. 4): Tr. 1 (100% H), Tr. 2 (70% SH and 30% H), Tr. 3 (70% SH and 30% S) and Tr. 4 (100% SH). Feed composition analysis for each treatment, and using SAS procedures statistical analysis of body weight gain (BWG) and dry matter intake (DMI) were carried out for each species and feed conversion rate (FCR) and average daily gain (ADG) were calculated. The results of sheep showed a significant difference ($p < 0.05$) among all treatments except between Tr. 2 and Tr. 3 for BW; and Tr. 1 was significantly different from Tr. 2 and Tr. 4 for DMI. However, these results were no different for goats among all treatments, with the exception DMI of Tr. 4. Therefore, the present study indicated that the inclusion of halophyte (up to 30%) in the diet can substitute the 30% S, which is expensive and readily unavailable, as alternative animal feed for small ruminants to fill the gap of feed shortage and non-availability in Eritrea. However, further study is necessary to see the impact of halophyte on milk production, fertility, meat quality and its economical use as animal feed.

Keywords Body weight • Feeding value • Goat • Halophyte • Sheep

19.1 Introduction

Eritrea is a sub-Saharan country in the Horn of Africa located from 12°40′ to 18°02′ N of latitude and from 36°30′ to 43°20′ E of longitude (Trevaskis 1975). The climatic diversity of the country varies from moist humid to hot arid and semi-desert conditions, with low and erratic rainfall distribution. Its annual rainfall varies

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between 200 and 700 mm. According to the recent agro-ecological classification (Amanuel et al. 2002), nearly 75% of Eritrean land mass is arid and semi-desert. The country is characterized by frequent droughts, low livestock and crop productivity and climatic diversity. The country is under a constant challenge to satisfy basic food security. About eighty percent of the livelihood of the people depends on agriculture, and thus there is a need to develop farming systems that can achieve basic food security.

Eritrea owns a wide range of livestock diversity. According to Animal Resources Department of MoA (ARD 1997) report livestock population is estimated to be about 2.0 million cattle, 6.1 million small ruminants, 0.3 million camels, 0.5 million equines, 1.1 million poultry and 4.5×10^3 million swine. Agriculture contributes 20% of the national GDP, of which 25% is from livestock production. Despite this contribution, livestock are not exploited efficiently for two main reasons: (1) the animal feed problem and (2) the livestock's potential is not identified or is uncharacterized. Livestock is believed to play a vital role toward self-sufficiency by providing food security substantially when the extensive traditional mode of production is transformed into modern livestock production and the animal feed problem is resolved.

In Eritrea, animal feed is the main bottleneck to livestock production especially in arid and semi-desert areas (75% of the total landmass) and during the dry season in the moist humid and hot sub-humid agro-ecological zones. Many attempts are underway to solve this problem so as to support robust livestock production. One of the attempts is to supplement livestock with feeds such as oil seedcakes and *shishay* (S), locally manufactured commercial feed. However, these feeds are expensive and are not readily available. Thus, to fill this gap, assessment of other alternative animal feeds for small ruminant is required. In arid and semi-arid lands where animal feed is scarce, livestock production declines. In such areas, it has been suggested by many scholars that planting halophyte pastures in saline dry lands, salt marshes and seawater can be a solution to alleviate the animal feed problem.

Eritrea has about 1,000 km of coastline, rich of naturally grown halophyte plants such as seaweeds, *salicornia* and mangroves. These natural resources, halophytes, are considered as potential animal feed but are not yet utilized as animal feed, though sometimes camels and goats are observed to browse on mangrove trees during the dry season. From this concept, halophyte as alternative animal feed is contemplated to fill the gap. Halophytes are salt tolerant plants in the soil-water environment. Halophyte species have different degree of tolerance to salinity (Daoud et al. 2001). The author further added that biomass production of halophyte is affected by the degree of salinity and seawater concentration. Thus, as the salinity and seawater concentration increase, biomass production decreases. Halophytes are classified as hydro-halophyte and xero-halophyte. Hydro-halophytes grow in aquatic condition or on wet soil such as mangroves and salt marsh species along coastlines, whereas xero-halophytes grow in saline soil habitats even in desert areas.

From reviewed literature, since many decades, researchers have been trying to illustrate the use of halophyte as potential animal feed for different livestock (Sokoloff et al. 1950; Kehar and Negi 1953; Morton 1965; Malik et al. 1966; Wahid 1968; Kurian and Patolia 1980; Janick et al. 1981; Perry 1981; Miyake and Kogo

1982; Glenn et al. 1992; Swingle et al. 1996; Kraidees et al. 1998; Sillence et al. 2005; Hassan 2006). Other researchers also described halophyte plants use as landscape management and nature conservation (Rodriguez and Sanchez-Arias 2008).

Therefore, the objective of the present study was: to determine the nutritive content of halophyte and its intake by small ruminants; to investigate the effect of halophyte offered as a complete diet or a supplement on the body weight gain (BWG) of small ruminants; and finally to compare the feeding value of halophyte with locally available animal feeds in Eritrea.

19.2 Material and Method

19.2.1 Research Site

Feeding trial was conducted at Gahtelay Ram Farm, located 70 km North of Asmara on the way to Massawa port. The research area (Fig. 19.1) is characterized by having an altitude range of 280–450 m above sea level, hot and dry climate with annual temperature of 35°C, reaching up to 45°C in April–August months, and it receives annual rainfall less than 200 mm during the rainy season (November–February).

19.2.2 Experimental Design and Animal Management

A total of 160 yearling sheep and goats (80 of each species with equal sexes) with average initial weight of 22.6 and 16.8 kg, respectively, were penned for 84 ex-

Fig. 19.1 Research site: Gahtelay Ram Farm

Table 19.1 Design of the experiment

Species by sex	Tr.			
	1	2	3	4
Buck	Pen 1	Pen 5	Pen 9	Pen 13
Ram	Pen 2	Pen 6	Pen 10	Pen 14
Does	Pen 3	Pen 7	Pen 11	Pen 15
Ewes	Pen 4	Pen 8	Pen 12	Pen 16

Tr. 1 (100% H), *Tr. 2* (70% SH and 30% H), *Tr. 3* (70% SH and 30% S) and *Tr. 4* (100% SH)
Tr treatment

perimental days (July–September 2004). To avoid a source of variation due to age, initial weight and area of origin, animals were systematically assigned to each of the four treatments, and before the start of the experiment statistical analysis was done for the initial body weight (BW) among all treatments and no significant difference was found. Then animals were randomly allocated into one of the four treatments. During the experimental time, further sex division was made on each treatment. This was not done to see the sex effect on BW but to avoid growth retardation that can happen during the experiment as a result of sex excitement and disturbance, and to control unwanted pregnancy (Table 19.1).

During the adaptation period animals were fed on hay ad libitum. The type and the proportion of feed used in the experiment were: Tr. 1—100% halophyte (H); Tr. 2—70% sorghum husk (SH) and 30% H; Tr. 3—70% SH and 30% *shishay* (S); Tr. 4—100% SH. The ration was thoroughly mixed before offering to animals, and mineral salts were added to Tr. 4. The above rations were given at a rate of 3% of the BW of animals on dry matter (DM) basis per day.

Measurement of feed offered, feed leftovers and animal BW were taken every week. Animal BW measurements were taken at empty gut-fill at early morning before small ruminants accessed to water and feed. Dry matter feed intake (DMI) was calculated as the difference of feed offered and feed leftover. Similarly, average daily body gains (ADG) were calculated as differences between final and initial BW divided by experimental days, and feed conversion ratio (FCR) was derived from the ratio of daily DMI and ADG.

19.2.3 Feed Composition Analysis and Statistical Analysis

The approximate nutritional value of the four treatment feeds was determined by chemical analysis. Samples of the four treatments from each pen were collected at weekly intervals, and were analyzed in the Nutrition Laboratory of the Ministry of Agriculture for proximate analysis to determine the contents of crude protein (CP), fat, crude fiber (CF), metabolizable energy (ME) ash per a unit of dry matter. The DMI and BW were analyzed using the General Linear Model (GLM) procedure of SAS (SAS 2001) for the four treatments as an experimental unit. Results of BW and

DMI are presented as the least square means (LSM) of the each treatment with their variance of standard error (SE).

19.3 Results and Discussion

19.3.1 Feed Composition Analysis

The chemical feed composition analysis on DM basis is presented in Table 19.2. The low and high value of CP in the present feed composition analysis was recorded in Tr. 1 and Tr. 3 respectively. This high CP and ME content in Tr. 3 appears to be probably due to the inclusion of S feed in the treatment. However, as per the low and high values of ash content, the reverse was found for Tr. 1 and Tr. 3. The CP content of the four treatments was found to be less than the ideal dietary CP (11%) requirement as reported by Kay and MacDearmid (1973) for normal weight gain of sheep and goats.

From the reviewed literature, halophyte foliages are reported to be more nutritious than alfalfa, clover, barley, cabbage, beetroot and sunflower feeds (Malik et al. 1966; Janick et al. 1981). The CP (7.65%) and ash (21.6%) content of Tr. 1 in this study was higher than the values obtained from three species of halophyte by Saifullah (1984): 4.18% and 16.3% of *Avicennia marina*, 5.35% and 10.02% of *Ceriops decandra* and 2.68% and 14% of *Rhizophora mucronata*, respectively. However, the salt content of the present study was less than the results for halophyte species reported by Sillence et al. (2005) and Swingle et al. (1996), which was in the range of 24–34% for values reported by the later author.

In a pairwise comparison, DMI results showed no significant difference between Tr. 1 and Tr. 3 and between Tr. 2 and Tr. 4 for sheep; and Tr. 4 was the only significantly different from other treatments for goats. In both species the lowest and highest DMI was recorded in Tr. 3 and Tr. 4 respectively. In a comparison, low feed intake was recorded in treatment with halophyte as a complete diet (Tr. 1) than halophyte as supplement (Tr. 2) for both species. This low feed intake in Tr. 1 is probably due to the fact that was reported by Sillence et al. (2005) who indicated that salt diets decrease feed intake and digestibility in ruminants.

Table 19.2 Feed composition analysis

Treatments		DM	Ash	CP	CF	Fat	ME
		%	%	%	%	%	kcal/kg DM
Tr.	1	91.5	21.59	7.65	9.29	3.45	2,431.9
	2	92.0	10.87	8.23	25.0	3.8	2,234.43
	3	92.0	6.25	10.61	20.11	4.38	2,528.16
	4	91.5	6.83	8.05	31.69	3.83	2,128.20
	Shishay[a]	90.5	5.25	16.30	7.18	4.25	3,099.92

[a] Locally manufactured commercial feed by Shishay Animal Feed Processing Plant
DM Dry Matter, *CP* Crude protein, *CF* Crude Fiber, *ME* Metabolizable Energy

19.3.2 *Body Measurement of Sheep and Goats*

BW, feed intake and feed conversion ratio measurements for sheep are presented in Table 19.3 while for goats they are presented in Table 19.4. Means of BW and feed intake along with their SE are presented.

Statistical analysis for means final BW measurement of sheep indicated that significant differences ($p < 0.05$) were found among treatments except between Tr. 2 and Tr. 3. However, the means final BW of goats were not significantly different ($p > 0.05$) among all treatments. Both species of small ruminants which ate halophyte as a complete diet (Tr. 1) responded with high BWG.

The DMI and ADG of ruminant animals are primarily influenced by the energy and protein content of the feed and feed digestibility. Sillence et al. (2005) indicated that salt diets lowered feed intake and digestibility. In contrary to the report presented by Sillence et al. (2005) that sheep growth depressed when salt concentration in a diet was above 12%, in the present study halophyte as a complete diet (Tr. 1) with highest ash content (21.59%) for both species showed better response in

Table 19.3 Means of body weight gain (BWG) and dry matter intake (DMI) with their standard error (SE), feed conversion ratio (FCR) measurements of sheep

Parameters	Tr.			
	1	2	3	4
Growth Measurements				
Mean Initial BWG (kg)*	22.6 ± 0.25^{f}	21.9 ± 0.30^{f}	21.6 ± 0.28^{f}	24.3 ± 0.29^{f}
Mean Final BWG (kg)*	32.0 ± 0.81^{a}	26.4 ± 0.46^{b}	27.3 ± 0.52^{b}	28.3 ± 0.34^{c}
ADG (g/day)	112.2	53.3	68.0	47.8
Intake Measurements				
Mean DMI/h/d (kg)*	0.54 ± 0.02^{a}	0.74 ± 0.02^{b}	0.51 ± 0.03^{a}	0.79 ± 0.3^{b}
FCR	4.8	13.9	7.5	16.5

ADG average daily gain, *DMI/h/d* dry matter intake per head per day

* No significant difference ($p > 0.05$) between means of treatments with the same superscript

Table 19.4 Means of body weight gain (BWG) and dry matter feed intake (DMI) with their standard error (SE), feed conversion ratio (FCR) measurements of goats

Parameters	Tr.			
	1	2	3	4
Growth Measurements				
Mean Initial BWG (kg)*	16.49 ± 0.02^{f}	16.85 ± 0.01^{f}	17.06 ± 0.05^{f}	16.88 ± 0.14^{f}
Mean Final BWG (kg)*	20.94 ± 0.40^{d}	19.06 ± 0.29^{d}	20.50 ± 0.31^{d}	20.65 ± 0.34^{d}
ADG (g/day)	53.0	26.3	40.9	44.9
Intake Measurements				
Mean DMI/h/d (kg)*	0.59 ± 0.3^{a}	0.64 ± 0.01^{a}	0.56 ± 0.02^{a}	0.75 ± 0.03^{b}
FCR	11.1	24.0	13.7	16.7

ADG average daily gain, *DMI/h/d* dry matter intake per head per day

* No significant difference ($p > 0.05$) between means of treatments with the same superscript

BWG as compared to other treatments, which was followed by Tr. 3 for sheep and by Tr. 4 for goats. This is probably due to the presence of high crude fiber in other treatments which reduce digestibility, and thus hampered the release of CP and energy nutrients to the animal. This fact seems clearly observed because as the crude fiber content increased in the order of Tr. 1, Tr. 3, Tr. 2 Tr. 4, the ADG of sheep was decreased in the same order. Generally, body gain response in goats across all treatments was found to be less than in sheep.

Many researchers highlighted that halophyte forages are potential as animal feed especially in arid and saline ecosystems, which are not suitable for other pasture production. A study by Kraidees et al. (1998) confirmed that inclusion of stem up to 30% and inclusion of spike up to 10% of halophyte (*Salicornia begelovi. Torr*) was beneficial as animal feed for growing lambs. This understanding was also substantiated by Swingle et al. (1996) who concluded that halophyte is an important animal feed at moderate inclusion levels. The non-significance in BWG between Tr. 2 and Tr. 3 for both species in the present study indicates that small ruminants fed on 30% halophyte in the diet were able to gain at almost the same rate as those small ruminants fed on 30% S in the diet. Thus, it can be interpreted that the inclusion of halophyte at 30% level in the diet can substitute the inclusion of S which is expensive and not readily available. Thus, halophyte as complete diet or as inclusion up to 30% in the basal diet can be used for maintaining sheep and goats in arid areas and during the long dry season with small ADG.

19.4 Conclusion

The present study indicated that halophyte as the critical nutrient for maintaining and enhancing growth of sheep and goats seem to be promising. In this respect halophyte either as complete or as moderate supplement diet can be used as an alternative animal feed for maintaining small ruminants with small body gain. However, further study is needed to see the impact of halophyte on fertility, milk production, meat quality and its economical use as animal feed.

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Chapter 20
The Effect of Feeding Ensilages of Poultry Litter with Leftover Bread on the Body Weight of Barka Cattle

Tekeste Abraham Tewoldebrhan and Goitom Asghedom

Abstract Litters from replacement birds, layers and broilers were collected; sun-dried and analyzed for the content of crude protein (CP), crude fiber (CF), ash and fat. The litters were ensiled with leftover bread in a ratio of 45.5: 54.5 by weight in plastic containers for a minimum of 21 days. The process of ensiling resulted in a product that had a higher CP content after ensiling. The ensilages were of wholesome appearance, palatable and safe. Sixteen Barka cattle were divided into groups of four cattle in each treatment and a 90 days trial was conducted. The treatments consisted of a control diet (T_1) consisting of a commercial type ration made up of 30% wheat bran, 36.3% leftover bread, 2.4% fishmeal, 30.3% taff straw and 1% salt. The other three treatments consisted of ensilages of 30% replacement litter (T_2); layer litter (T_3) or broiler litter (T_4) with leftover bread 36.3%, fishmeal 2.4%, taff straw 30.3% and salt 1%. The feeding system was restricted and all the groups consumed all the feed that was offered to them (7.44 kg of DM per cattle per day). Average body weight gains (ABG) for T_1, T_2, T_3 and T_4 were 1.093, 1.019, 0.673 and 0.966 kg/day, respectively. ABG for T_1, T_2 and T_4 were not significantly different ($p > 0.05$), whereas cattle fed on T_3 were significantly different ($p < 0.05$) from ABG of T_1, T_2 and T_4. Wheat bran can be completely replaced by replacement and broiler litters in rations for Barka cattle.

Keywords Barka cattle • Leftover bread • Ensiling • Poultry litter • Wheat bran

20.1 Introduction

The major problem for meat production across the country like Eritrea is unavailability and inadequacy of feed. Hence the main challenge is how to increase feed supply and improve feeding practices. The conventional grain feeding diets are very

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expensive and there is an urgent need to explore alternative feeding systems. One such alternative that can be widely available in the country is poultry waste. The utilization of this resource offers a significant reduction in feed cost and also minimizes the requirements for expensive protein feeds and other feed resources, such as cereal grains and milling by products (Shah and Muller 1982).

Poultry wastes are rich in crude protein (CP) and minerals. Due to the high fiber and non-protein nitrogen content of the waste, ruminants are best suited for utilization of poultry wastes. Processing of poultry litter is necessary for destruction of pathogens, improvement of handling and storage characteristics, and maintenance or enhancement of palatability (Fontenot 1996). The ensiling of poultry waste is a simple, low-cost technique, and to ensile poultry litter, a rich source of fermentable carbohydrate must be added to obtain a palatable product. Protein-rich feeds having a low energy content, such as poultry litter, fishmeal and cassava leaves can be successfully ensiled when mixed with one or several energy-rich products (fermentable carbohydrate) such as root crops, rejected bananas, spent grains or molasses (Kayouli and Lee 2000).

In this study, leftover bread was used as the source of fermentable carbohydrate. Leftover bread (bakery waste) can be obtained from cafeterias, restaurants, hospitals, snack bars, military camps, police stations and similar institutions. Poultry waste can be incorporated in beef cattle rations up to a maximum of 40% DM of the complete diet without affecting overall performance (Muller 1984). The objectives of the study were to examine the effect of ensiled poultry litter with leftover bread on the body weight gain of cattle and to compare the effect of the different kinds of poultry litters (layer, replacement and broiler) on the body weight gain of cattle.

20.2 Materials and Methods

Layer litter was collected from two small-scale farms, dried in the sun and mixed thoroughly. The replacement and broiler litters were collected from two separate commercial farms. After collection, the litter was sun-dried for 2 days by spreading on plastic sheets. The poultry litters were a mixture of bird excreta, wasted feed, feathers and bedding materials such as sawdust, wood shavings and straw. The litters were rid of other foreign material when they were sun-dried. Samples of the collected litters were subjected to laboratory diagnosis for salmonellosis analysis immediately after the collection. Leftover bread was collected from different areas, sun-dried and ground. In total, about 5 t of leftover bread was collected.

The leftover bread and poultry litter were separately weighed and mixed. The mixture was composed of 45.5% poultry litter and 54.5% leftover bread on dry mater basis. Water (80 l/100 kg mixture) was added to raise the moisture content to about 50%. Filling and compaction of the silage in the plastic containers was done by hand. The mixtures of poultry litter and leftover bread were firmly packed and pressed into the plastic containers. A plastic sheet was inserted between the lids of the containers and the ensiled material to ensure airtight sealing. The silage was prepared daily and each container was opened after a period of at least 21 days.

Sixteen Brake cattle having the same weight and age (3–4 years) were divided into four treatment groups after balancing for weight. The four groups were randomly allocated to either the control group or the silage group by drawing lots. The partition between the groups was made from locally available wooden posts with sufficient space allowing all animals to eat at the same time. The control group (T_1) received a commercial type ration consisting of 30% wheat bran, 36.3% leftover bread, 2.4% fishmeal, 30.3% taff straw and 1% salt on dry matter (DM) basis. The other three silage groups (T_2, T_3 and T_4) received 36.3% leftover bread, 2.4% fishmeal, 30.3% taff straw, 1% mineral and 30% replacement, layer or broiler litter, respectively ensiled with leftover bread (36.3%).

Feed was offered in two equal portions daily. Each treatment group received the same amount of dry matter intake (DMI). The aim of the study was to see the effect of poultry litter as a protein supplement on the body weight of cattle. To avoid the effect of variable amount of energy on the body weight of the animal, the rations were made almost isocaloric for all treatment groups. The research was conducted for 105 days feeding period including a 15 days adaptation period. Leftover from the treatment feeds were collected and weighed daily. Animals were weighed every two weeks. All the animals had free access to water at all times.

DM, CP (Kjeldahl-Nx6.25), fat, crude fiber (CF) and ash in the different kinds of poultry litters (replacement, layer and broiler litter) and the ingredients used in the control diet were analyzed according to standard procedures described by the Association of Official Analytic Chemists (AOAC 1984). The trials were designed according to a completely randomized design (CRD). Live weight gain and DMI in terms of metabolic weight of the animals were analyzed using one-way analysis of variance.

20.3 Results and Discussion

Chemical Composition of sun-dried poultry litters used in the feeding trial is given in Table 20.1.

Table 20.1 Chemical composition of sun-dried poultry litters used in the feeding trial

Component	Replacement litter	Layer litter	Broiler litter
Dry matter	90.00	92.32	82.32
Crude protein (% DM)	21.15	18.59	18.03
Ash (% DM)	14.54	38.56	16.79
Crude fiber (% DM)	10.49	8.76	26.44
Ether extract (% DM)	0.90	2.80	1.59
NFE (% DM)	52.92	31.29	37.15
Energy (MJ/kg DM)[a]	12.74	9.40	9.83

[a] Calculated value

Sun-dried samples of poultry litters were taken for laboratory analysis. The CP content for replacement litter was higher than that for layer and broiler litters, whereas CP content of layer and broiler litters were quite similar.

The CP content of broiler litter used in this study is not in agreement with Deshck et al. (1998) who found a higher CP content in broiler litter. For this study the broiler litter used was of 2 months of age before it was ensiled. Since it was collected after the birds were sold, consequently the litter may have deteriorated in nutritive value, especially in the CP content.

On the other hand, the high content of CF in broiler litter could have come from too much bedding material (sawdust) in the broiler litter resulting also in lowering the CP content. The replacement and layer litters were similar in their CP content (Table 20.1) with those found by other workers. Muller (1984) reported the CP content of layers litter to range from 16–22%, while Deshck et al. (1998) obtained a range of 16.4–30.6%. The CP content for replacement litter obtained 20% (Muller 1984).

Ash values for replacement, layer and broiler litters (Table 20.1) were 14.54, 38.56, and 16.79%, respectively. Ash for layer litter was more than twice as much as that of the replacement and broiler litters. Deshck et al. (1998) obtained a range of 17.8–49.8% and the high ash content of layer litter is due to the high content of Ca (3.5–4% of ration DM) and insoluble grit. Muller (1984) reported that poultry feed, bird excrement, bedding material and soil are the main ash contributors in poultry litter.

The nitrogen free extract (NFE) values for replacement, layer and broiler litters were 52.92, 31.29 and 37.15%, respectively. NFE for replacement litter was higher than those for layer and broiler litters. The energy content in MJ/kg of the litters for replacement, layer and broiler were 12.74, 9.40 and 9.83, respectively. The energy content of the replacement litter was higher than both the layer and broiler litters, whereas the energy content of layer and broiler litters were similar. The reason for the higher energy content of replacement litter than the broiler litter could be the presence of spilled feed in the litter. The cause of the low energy content of the broiler litter could be the high fiber content which could have come from a proportionally high content of sawdust in the litter. Four different samples of sun-dried poultry litters were determined for Salmonellosis. A specific culture media for *Salmonella* was prepared for growth, but *Salmonella* were not detected in all sun-dried poultry litters (layer, replacement or broiler litters).

Leftover bread ensiled with the three different kinds of poultry litters resulted in silage that was wholesome, of consistent colour and had a pleasant aroma. No mould growth was observed because the plastic containers had lids that ensured airtight sealing. Furthermore, the high ratio of leftover bread to poultry litter (3:2.5) ensured that there was enough starch for adequate fermentation. A pleasant aroma, indicative of an adequate fermentation was smelled in all the silages. There is no mention in the literature of workers who ensiled poultry litter with leftover bread.

The DM content of the materials in all silages was about 50%, since water was added during the ensiling process. The CP content (Table 20.2) in the ensilages for replacement, layer and broiler litters were elevated to 21.36, 19.47 and 17.94%, respectively, from 16.44, 15.27 and 15.02%, for the respective mixtures of litter and

Table 20.2 Chemical composition of ensilages for replacement, layer and broiler litters

Component	Leftover bread—Replacement litter	Leftover bread—Layer litter	Leftover bread—Broiler litter
Dry matter	48.99	47.77	50.14
Crude protein (% DM)	21.36	19.47	17.94
Ash (% DM)	10.20	20.78	11.81
Crude fiber (% DM)	7.34	6.84	16.36
Ether extract (% DM)	1.14	0.68	0.64
NFE (% DM)	59.96	52.23	53.25
Energy (MJ/kg DM)[a]	14.04	12.26	12.16

[a] Calculated value

leftover bread before ensiling. The increased CP value in all ensiled litters could be due to the lactic acid bacteria themselves being used as a source of protein after being lysed by the low pH in the stable phase of fermentation. Other researchers also found a higher content of CP after fermentation but did not mention the reason for the increase. Rasool et al. (1997) reported a similar increase in total nitrogen content of the silage containing 30% poultry litter. The CP value of the silages in the present study was similar to that reported by many authors who ensiled poultry litter with different feeds: Ibewochi and Echumba (1996) with cassava and sorghum flour, Hadjipanayiotou (1994) with olive cake and tomato pulp, Caswell et al. (1977) with corn grain. The CP content of the replacement litter ensilage was higher than those for layer and broiler litters. The reason for the lower than expected CP content in broiler litter could be due to the continued proteolytic activity and the high content of CF coming possibly from a high content of sawdust (bedding) in the litter.

On the other hand, the energy content (MJ/kg) of the silages for replacement, layer and broiler decreased to 14.04, 12.26 and 12.16, respectively, from 14.59, 13.07 and 13.26 MJ/kg, respectively, in the original mixtures before ensiling. There is a decrease in energy content in all processes involving ensiling. This is due to the production of heat and energy during the aerobic phase of fermentation. Pond et al. (1995) and Muller (1984) reported that during the short aerobic fermentation, there is a loss of energy due to resultant heat produced. During this stage the activity of lactic acid bacteria is low. The ensilage for replacement litter was higher in energy content than the ensiled layer and broiler litters, whereas the energy content in ensiled layer and broiler litters were almost similar. The decreases in energy in ensiled litters were reported by Caswell et al. (1977).

The silages were offered to the animals by mixing them thoroughly with taff straw to avoid selection. All the silages were palatable and eagerly consumed by the animals. All the Barka cattle adapted to the ensilages of the poultry litters after 3–5 days.

The feeding system was restricted. DMIs were 7.41, 7.40, 7.41 and 7.41 kg/day for the animals fed the control diet (T_1), ensiled leftover bread with replacement litter (T_2), ensiled leftover bread with layer litter (T_3) and ensiled leftover bread with broiler litter (T_4), respectively. Caswell et al. (1977) found a similar result where DMI for ensiled broiler litters were not significantly different from those fed

Table 20.3 Effect of feeding the different treatments on the body weight gain of Barka cattle

Parameter	T_1	T_2	T_3	T_4	LSD
Number of animals	4	4[*]	4	4	
Live weight (kg)—Initial	293.9	293.4	291.7	290.9	
Live weight (kg)—Final	392.3	390.7	352.3	377.8	
Feeding period (days)	90	90	90	90	
Average daily gain (ADG) (kg/day)	1.093[a]	1.019[a]	0.673[b]	0.966[a]	0.2264

T_1 Wheat bran + leftover bread + fishmeal + taff straw (control diets), T_2 Ensilage of leftover bread with replacement litter + fishmeal + taff straw, T_3 Ensilage of leftover bread with layer litter + fishmeal + taff straw, T_4 Ensilage of leftover bread with broiler litter + fishmeal + taff straw, *LSD* Least significant difference

[*] One animal was lost from the group and was not replaced

[a,b] Number in a row with different superscripts differ significantly ($p < 0.05$)

soybean meal. Other researchers (Al-Rokayan et al. 1998) also reported that the addition of poultry litter had a positive effect on DMI.

DMI of metabolic weight expressed as grams per unit of metabolic size ($W_{kg}^{0.75}$) per day were 91.4, 92.7, 97.1 and 94.1 for the T_1, T_2, T_3 and T_4, respectively. Intakes in terms of metabolic weight were not statistically different ($p > 0.05$) from treatment to treatments. A restricted system of feeding was employed. All the offered feed was consumed by all groups.

Cattle in all the four treatments gained weight throughout experimental period (Fig. 20.1). Cattle fed on T_1, T_2, T_3 and T_4 gained 1.093, 1.019, 0.673 and 0.966 kg/day, respectively. Differences for weight gains obtained for T_1, T_2 and T_4 were not statistically significantly different ($p > 0.05$) from one another (Table 20.3). Weight gain obtained for cattle fed T_3 was significantly different ($p < 0.05$) from cattle fed T_1, T_2 and T_4. Even though cattle fed on the control diet (T_1) gained a little bit higher than cattle fed ensiled replacement and broiler litters, it was not statistically different ($p > 0.05$). In the treatments in which replacement litter and broiler litters completely replaced the wheat bran, similar body weight gains were obtained as in the ration in which wheat bran was included (T_1).

The body weight gains obtained in this study are similar to results obtained in Kenya. Odhuba (1986) fed steers ensiled layer litter with sorghum forage and the steers gained 0.98 kg/day, whereas steers fed cottonseed cake gained 1.10 kg/day. The difference between the two diets was not statistically significant. Results similar to the present study have also been reported (Odhuba et al. 1986) using steers grazed in daytime and supplemented 2 kg ground sorghum grain and 1 kg containing 0, 40, 70, 100% broiler litter mixed with sunflower seed cake (SSC). They found that differences in weight gain, fat content and carcass grade of steers supplemented with either SSC or broiler litter based ration were not significant. Hadjipanayiotou et al. (1993) found that bull caves fed ensiled maize forage with poultry litter gained a slightly more weight than the control group (fed more cottonseed hulls and concentrates), but differences were not statistically significant.

Cattle fed on T_2 gained more than the other silage groups (T_3 and T_4). Table 20.2 shows that the ensilage for replacement litter was higher in CP content (21.36%)

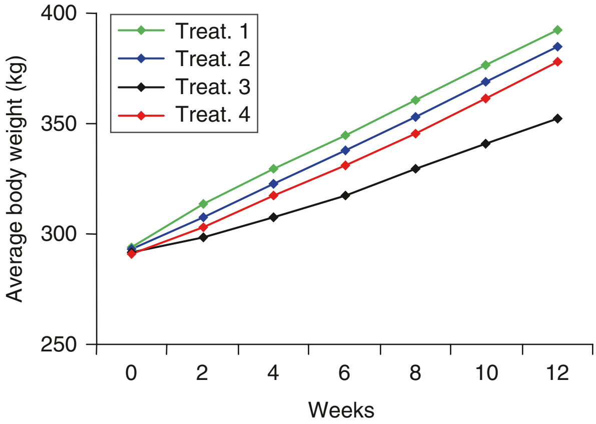

Fig. 20.1 Weekly average body weight of cattle fed a conventional feedlot type control diet or ensilages of poultry litters with leftover bread

than the ensilage for layer litter (19.47%) and broiler litter (17.94%). The ensilage for replacement litter was also higher in ether extract and lower in ash content than the other two ensilages. These could be the reasons that animals fed ensilages of replacement litter gained higher than the other two silage groups.

The ash content of the ensilage of layer litter (Table 20.2) was higher than that for replacement and broiler litters. Accordingly, cattle fed T_3 (ensilage of layer litter) gained less than the other two silage groups (T_2 and T_4). Minerals are required in trace amounts. If they are fed in slight excess of the requirements, they are excreted from the body. The increase in ash content and its consequences have also been observed by other researchers. Odhuba (1986), Muller (1984), Shah and Muller (1982) found that the high ash content of layer litter reduced the level of organic matter and digestibility and was responsible for its low metabolizable energy. Furthermore, Parsons (2006) reported that meals that contain higher ash resulted in poorer amino acid balance.

20.4 Conclusion

The results of this study show that properly prepared ensilage of poultry litter (replacement, layer or broiler) and leftover bread has a pleasant aroma and wholesome appearance, is a safe and palatable feed for livestock. Furthermore, cattle fed ensiled replacement and broiler litter making 30% of the ration gained 93.23% and 88.38%, respectively, of the body weight gained by those fed conventional feedlot type of diet, which included 30% wheat bran.

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Postface

The 2009 International Conference on The Integration of Sustainable Agriculture, Rural Development, and Ecosystems in the Context of Food Insecurity, Climate Change, and Energy Crises, held in Agadir in November 2009, was seen as one of the most important events investigating sustainable agriculture in the context of climate change and food security. The conference stressed that sustainable agriculture must be studied with an eco-system approach, where soil–water–plant–environment–living beings live in harmony with a well-balanced equilibrium of food chains and their related energy balances. Climate change impact is a major threat to accomplishing such an eco-system approach. To address climate change impact, it is important to adopt a holistic system approach, rather than individual efforts, to model climate change variability, rainfall distribution and patterns, temperature and land use changes. We need to focus on diagnosing the vulnerability of agricultural systems to climate change and develop adaptation pathways for affected systems. These efforts should be highlighted at the higher levels of policy making in order to develop strategies for mitigation and adaptation. Mitigation strategies involve decreasing the emission of greenhouse gases, and adaptation is about how agriculture, including livestock production, can make changes in order to survive in a world of uncertain weather systems and likely increased water and energy scarcity.

Water scarcity is indeed seen as the main constraint in climate change adaptation. Worldwide 70% of water withdrawals are used for agriculture. It is therefore, important to develop adaptation strategies to deal with climate change impact through managing water availability, agricultural intensification and environmental protection. One of the challenges will be to increase productivity whilst protecting the environment and the wellbeing of livestock. Whereas there is still some possibility of increasing crop yields, many species of farmed animals have already been pushed to their physiological limits by selective breeding for productivity parameters. This can be seen most obviously in the high-yielding Holstein-type dairy cows and in the fast-growing meat chickens now so ubiquitous all over the world. However, improved feeding and health regimes for livestock in developing countries will undoubtedly pay dividends.

It is envisaged that the global population will increase by 2 billion in the next 20 years. At the same time, climate change will impact both on total rainfall and

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seasonal distribution affecting cropping patterns, declining yields, causing decline in biodiversity and causing sea level rise, which will disturb the coastal communities and agriculture. Burgeoning urbanization, land grabbing and land degradation will result in the loss of some productive lands, the devotion of more land to biofuels production and increasing water demands on wetlands supporting valuable ecosystem services. All these factors will combine to threaten agriculture enhancement and food security. Albeit, using innovations in agriculture, it may be possible to produce more food, there is a danger that today's food production and environmental trends, if continued, will lead to food crises in many parts of the world, specifically the poor developing world. The synthesis report of the Agadir conference provides comprehensive recommendations for future research; however, it is important to identify agriculture technologies that can be out-scaled rapidly to other areas with similar agro-ecologies and system properties, so the research findings will spread rapidly to be adopted most widely as a way forward for adaptation to climate change impact.

The climate change would affect the most those sub-Saharan African countries which are dependent on rain-fed agriculture and "dry-land farming", and where productivity is generally less than the half of that of countries with irrigated systems. In dry-land agriculture, where water scarcity and land fragility are most severe, high productivity stops being the primary driver in agro-ecosystem management. Climate change will further intensify the pressure on dry-land agriculture.

The Agadir conference has identified following key issues for immediate consideration regarding climate change adaptation, sustainable agriculture and food security: a need to create a paradigm shift in agricultural policies; reforming food aid policies; investment in agriculture research; development and extension; rewarding the agriculture profession by promoting beneficial price regimes; ensuring research leading to appropriate biotechnology advances and innovations; strengthening of agricultural systems; bringing abandoned lands into production whilst preserving forests; provision of affordable credits to farmers; favourable free trade agreements between developed and developing countries; reforming policies on bio-energy production; improving livestock welfare; combating desertification and scientific soil information; and the creation of a North–South Sustainability Forum.

As a follow up to the 2009 Agadir conference and its documentation, an international conference on "Climate Change, Agri-Food, Fisheries, and Ecosystems: Reinventing Research, Innovation, and Policy Agendas for Environmentally- and Socially-Balanced Growth" (ICCAFFE2011) will be organized by the Faculty of Law, Economics and Social Sciences of Agadir, NRCS and GTZ on May 19–21, 2011, which will be an excellent forum for all interested parties (with a focus on decision-making actors and experts) to share latest development with relation to the conference themes, and conceive future policy and research agendas within the context of post-Copenhagen and Cancún era.

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