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An estimation of grain legume seed system efficiency in developing countries

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AN ESTIMATION OF GRAIN LEGUME SEED SYSTEM EFFICIENCY IN DEVELOPING COUNTRIES

BY

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ABSTRACT

Despite changes in agricultural policies, particularly shifts towards liberalization of seed sectors in developing countries, smallholder farmers persistently cite access to quality seeds as a major constraint to raising production volume and productivity, especially for grain legumes. Yet, current food production needs to nearly double to feed the rapidly growing world population. Also, agriculture is expected to lift hundreds of millions of people out of poverty and undernutrition in the developing world. These challenges are further compounded by diminishing natural resources and increased frequencies of climate-change associated weather extremes. Plant breeders have developed varieties for these extremes, but still need robust seed delivery systems to ensure positive impacts on millions of smallholder farmers. Unlike maize seed systems that have experienced tremendous gains over the past decades, grain legume seed systems have remained rudimentary and continue to face numerous demand-and supply-related challenges. Out of the various legume seed delivery models currently available, it is imperative to identify and prioritize the most efficient ones for cost effective outcomes given the limited financial resources faced by developing countries. There is a general dearth of knowledge, methodologies and understanding of the parameters to monitor in this regard. This paper presents an overview of current metrics to measure performance of the seed systems in general while proffering a number of weighted indicators to holistically assess efficiency of grain legume seed systems in developing countries.

Key words: **seed system, efficiency indicators, seed access, seed quality, sustainability, genetic diversity, smallholder farmers.**

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ABDI	Agrobiodiversity Index
ACTESA	Alliance For Commodity Trade In Eastern And Southern Africa
AFSA	Alliance for Food Sovereignty in Africa
AGRA	Alliance for a Green Revolution in Africa
AOSCA	Association of Official Seed Certifying Agencies
ARC	Agricultural Research Council
ASA	Agricultural Seed Authority
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
ASF	Access to Seeds Foundation
ATSI	Access to Seeds Index
BGMF	Bill & Melinda Gates Foundation
CBD	Convention on Biological Diversity.
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture
CIHI	Canadian Institute for Health Information
COMESA	Common Market for East and Southern Africa
CSP	Community Seed Production
DIIVA	Diffusion and Impact of Improved Varieties in Africa
DNA	Deoxyribonucleic acid
EBA	Enabling Business in Agriculture
EGS	Early generation seed
FAO	Food and Agriculture Organization of the United Nations
FGD	Focus group discussion

FPVS	Participatory variety evaluation and selections
HDR	Human Development Report
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
ICARDA	International Center for Agricultural Research in the Dry Areas
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
IPPC	International Plant Protection Convention
ISAAA	International Service for the Acquisition of Agri-biotech Applications
ISF	International Seed Federation
ISSD	Integrated Seed Sector Development
ISTA	International Seed Testing Association
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
KII	Key informant interview
KIT	Royal Tropical Institute
LSMS-ISA	Living Standards Measurement Study-Integrated Surveys on Agriculture
NARS	National agricultural research systems
NGO	Non-governmental organizations
ODI	Overseas Development Institute
OECD	Organization for Economic Development and Co-operation
PABRA	Pan Africa Bean Research Alliance

PBR	Plant Breeders' Rights
QDS	Quality Declared Seed
ROI	Return on investment
SADC	Southern Africa Development Community
SSA	Sub-Saharan Africa
TASAI	The African Seeds Access Index
TRIVSA	Tracking Improved Varieties in South Asia
UNDP	United Nations Development Programme
UPOV	International Union for the Protection of New Varieties of Plants
WB	World Bank

INTRODUCTION

Discussions around climate change have become topical in recent years; there is clear evidence that droughts are more frequent, higher than average temperatures have become common place and water resources have become scarcer than before (UNDP, 2014).These changes leave millions of farmers unable to adapt or cope; leaving agriculture in doldrums. Agriculture is responsible for 70% of all water withdrawals, accounts for approximately 85% of ground water and surface water consumption and it is estimated that the planetary boundary for global freshwater use has been reached (Rockström et al., 2009). Also, according to the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) Report, agriculture produces 30% of the global greenhouse gas emissions that contribute to global warming (Hurni and Osman-Elasha, 2009).

Meanwhile, records and climate modelling predict reductions in suitable cropping areas and yields for crops such as wheat (*Triticum aestivum* L.) (Lobell et al., 2011a), maize (*Zea mays* L.) (Lobell et al., 2011b) and the common bean (*Phaseolus vulgaris* L.) (Ramirez-Villegas and Beebe, 2013) due to global warming. This presents a gloomy future over the requirement to nearly double current food production to cope with the rapidly growing world population, which is expected to be more than nine billion by the year 2050. Meanwhile, projections indicate that 80 percent of the increases in food production in the developing world will come from increases in yields and cropping intensity, and only 20 percent from expansion of arable land (FAO, 2009). Also, agriculture, which is three times more efficient in reducing poverty than other sectors (World Bank, 2008; Barrett et al, 2010), is expected to take hundreds of millions of people out of poverty and malnutrition in the developing world, where more than 500 million smallholder farmers live (Ravallion et al, 2007) and produce 80 percent of the food for Africa and Asia. Studies have also shown that climate change has more devastating impacts on household nutrition in developing countries (Carpena, 2019), and undernutrition causes productivity losses and healthcare costs amounting to US$2.1 trillion per year (FAO, 2013), yet grain legumes when combined with other staples, can be pivotal in combating the challenge and help transform food systems.

It has been observed that over the past few decades, national diets have been converging into a globalized diet (Khoury, 2015) as the world continues to rely on an ever-decreasing number of major staple crops. The intensified production of only a handful of staples, especially modern varieties that are genetically related, brings agronomic, ecological, nutritional and economic risks (Edelman et al., 2014). This unsustainable intensification has downplayed the contributions of grain legumes to human diets, yet there is strong evidence that productivity of the globally dominant cereals such as rice, wheat and maize is projected to decline by 45 to 72 percent of current yields by the year 2100 due to climate change and a diminishing natural resource base (Adhikari et al., 2015).

Current global discourse on food production and food systems is on diversification for sustainability. Grain legumes fit well in the current sustainable food system strategies aimed at reducing the carbon footprint for protein production if more land is diverted from livestock production to grain legume production. Furthermore, consumption of a diverse array of legumes is important in the human diet; the crops are already an essential source of vitamins, micronutrients and protein for large parts of the developing world (FAO, 2013), correspondingly, grain legumes are associated with the developing world and smallholder farmers. In recognition of the contribution of legumes to human diets, 2016 was declared by the United Nations as the International Year of Pulses (grain legumes), and celebrated under the banner "nutritious seeds for a sustainable future". Legumes are widely considered a possible swap for meat as a source of protein due to their texture and flavour. To highlight this possibility, 11 out of the 50 future crops are legumes (World Wildlife Fund and Knorr, 2019). Also grain legumes reduce greenhouse gas emissions (Drinkwater et al., 1998) when they precede cereals in cropping systems, and have been a key rotational crop for large scale farming where gross margins are higher compared to smallholder farming due higher yields and economies of scale (Rawal and Cluff, 2019). In smallholder farming on the other hand, high uncertainty due to poor market infrastructure and continued use of unimproved varieties and low quality seed limit intensification of grain legume production. In this paper, the term “seed” is used *sensu lado* to define all planting materials that farmers use to produce legume crops, which may not be recognised as seed *sensu stricto*.

The challenges in legumes seed supply are related to the biology of legume crops. First, the seed of some legumes is quite bulky and therefore costly to transport – high seed rates per hectare are required for planting. Second, the seed of some legumes deteriorates very fast in storage due to high oil content. Third, most legumes, except recent pigeon pea hybrids (Saxena et al, 2013) are self-pollinating and do not benefit from hybridization (heterosis); farmers may save their own seed with negligible yield penalty compared to hybrid crops. As a result, private sector investments in the legume seed sector tend to be very limited. For instance, despite progress in the Indian seed sector, the public sector continues to dominate the supply of self-pollinating varieties (FAO, 2010). Similarly, following reforms and privatization of the seed sector in sub-Saharan Africa (SSA), emerging seed companies tend to focus on the lucrative maize hybrid seed business at the expense of legumes (Mabaya et al, 2013). Legume seed supply has therefore, remained underdeveloped and a responsibility of the public sector by default and a number of non-governmental organizations (NGOs) operating various projects, some of which are humanitarian and operate on a start-stop basis. Also, farmer-to-farmer dissemination and various other models (Sperling et al., 2017) have emerged to support legume seed dissemination for enhanced food and nutrition security, incomes and resilience to climate change. All these various channels are meant to deliver modern and diverse legume cultivars that match the farmers’ biophysical and socioeconomic contexts. Well-functioning legume seed systems are therefore central to delivering these traits to farmers' fields. It is therefore critical to understand which supply channels work better for further scaling and mainstreaming.

Also, to cope with climate change there is need for rapid deployment of appropriate cultivars in cost effective and sustainable manner. In this document, the term "seed system" denotes the sum of activities and interactions between physical, organisational and institutional components that define farmers' access and use of seed, with reference to grain legume crops. Over the years, the terms "efficient", "sustainable", "improved", "robust", and "effective" have been used, often interchangeably, to describe seed systems of various crops, but without clarity on the assessment methodology. In most cases the definitions often focus on one of the three components; performance, structure and conduct without considering the overall goal of the seed system. On the other hand, seed systems have been equated to a treadmill (Remington et al., 2002) for lacking clear progress, especially making the desired impact on livelihoods.

This paper attempts to expose the gaps in the methods and data currently used to evaluate the efficiency of grain seed systems. It then defines a list of possible efficiency indicators and their weights based on the author's understanding. Understanding the methodology for assessing the efficiency of seed systems is key in guiding impact assessments, practitioners and other stakeholders to allocate resources better to improve outcomes of their efforts in seed systems.

In summary, the objectives of this paper are:

i. Provide a background to current legume seed systems, evaluation methods and their shortcomings
ii. Propose a list of indicators and their weights for assessing grain legume seed system efficiency
iii. Provide a framework which can be used by practitioners to evaluate grain legume seed systems and contribute instruments for seed system performance

LITERATURE REVIEW

The Importance of Grain Legumes

Grain legumes have been part of human tradition and culture since ancient times; they were among the first domesticated plants, and possibly before maize (FAO, 2016a). They are grown in almost every climatic region, except the poles and the infertile desert. SSA and Asia produce 50% of the global pulse volume. Unlike cereals, that mostly grown on prime land, legumes are grown a wide range of soil types, in areas with erratic rainfall or lands where other crops are likely to fail or produce low yields. Legumes, therefore occupy a special niche in global agriculture and have been exchanged across all continents. They bring numerous benefits to more than 100 million producers and hundreds of millions of consumers worldwide, especially in the world's largest producer and consumer, India (Rawal and Cluff, 2019).

Legumes have the ability to fix atmospheric nitrogen into the soil (Bagayoko et al., 2000: Sainju et al., 2005) and free up soil-bound phosphorous (FAO, 2016a). These pro-low-input characteristics and the compatibility in various cropping systems such as rotations, intercropping and relay cropping bring preference to legume production by smallholder farmers. Species diversity in the various multiple cropping systems promotes efficient use of water, light, nutrients and other resources, and reduces the risk of total crop failure.

Apart from being important components of cropping systems, grain legumes are also essential in human diets and nutrition. Global per capita consumption of legumes has been suboptimal and static at around 21g per day since the 1980s (Rawal et al., 2019), but is highest in Latin America and the Caribbean at 34 g per capita per day followed by SSA and South Asia at joint 33g per capita per day and lowest in Caucasus and Central Asia at 1g per capita per day (Rawal et al., 2019). Legumes are an important source of dietary protein, especially in developing countries that have low animal protein consumption (FAO, 2013: UNDP, 2013: UNDP, 2014).

Globally, grain legumes contribute about 6% of protein intake and 3% of total dietary energy. According to an analysis performed based on the U.S. dollar producer prices, legumes provide up to eleven times more protein and twenty times more calories than meats. Compared to cereals, legumes also provide a similar level of calories, but higher dietary fibre and minerals than all the major cereals (Rawal et al., 2019) while providing up to three times the amount of protein found in rice and wheat (BGMF, 2012). They form a whole meal and can therefore be used to prevent protein energy malnutrition among children and infants; 27 % of countries that have food-based dietary guidelines recognise pulses as high protein food (Rawal et al., 2019). From a health perspective, consumption of legumes also reduces the risks associated with major chronic diseases such as cancer, obesity, cardiovascular disease, diabetes and gut health (Kushi et al., 1999; Stephenson et al., 2017).

In recent times there has been growing interest in legume production for trade and smallholder incomes. Grain legume production increased by 20 million tonnes between 2001 and 2014 (Rawal and Cluff, 2019) while internationally traded volume as a percentage of production grew from 4% in 1971 to 18 % in 2013 (Belhassen et al., 2019). These increases originated from huge gains in common bean and cowpea (*Vigna unguiculata* (L.) Walp.) production in Africa (Snapp et al., 2018) and chickpea (*Cicer arietinum*) in India (Belhassen et al., 2019), albeit from an increase in cropping area rather than productivity.

Despite the increases, there is a gap between legume production and consumption needs - legumes only occupy 25 % of land area allocated to cereals. Pulses have been misconstrued as food for the poor and there has been a general notion that people shift to better sources of protein with affluence, resulting biased research prioritization between cereals and grain legumes in both developed and developing countries. For instance, in 1994 the United States had 207 scientific personnel years working in legumes breeding research and development compared to 892 in cereals (Frey, 1996). Correspondingly, global cereal production has almost tripled over the past 50 years while grain legume production has only increased by about 60%. Similarly, between 1971 and 2014, grain legume yield only increased by 38.7% compared to 112 % for cereals (Belhassen et al., 2019). The limited production therefore impacts negatively on the affordability and consumption of legumes (Larochelle et al., 2017). Efforts to increase production for the benefits highlighted should also address the lengthy cooking requirements, given the steep increases in energy costs in many developing countries. From the foregoing, legumes are an ideal for sustainable agriculture (FAO, 2016a), but some research gaps need to be addressed to make them more appealing to producers.

Recent improvements in Grain legumes

There is a wide variability in legume genetic resources that can be tapped by plant breeders for crop improvement through traditional techniques and recombinant DNA methods to help farmers cope with climate change. Apart from increasing productivity, plant breeders now use molecular and genetic techniques to selectively identify phenotypes and genotypes that are associated with other traits of interest. Such functional genomic tools help plant breeders to efficiently utilize available germplasm to effectively enhance genetic gains within short periods of time. These high-throughput systems and the use of digital tools have enable easier identification and advancing of genotypes with preferred traits. Some of the key traits include tolerance to biotic, abiotic and edaphic stresses, and nutritional quality in light of the shifts brought about by climate change. For instance the discovery of variation in the ability to scavenge and accumulate micronutrients, iron and zinc in common bean (Blair *et al.*, 2009) has led to breakthroughs breeding for high mineral content, a process that in now widely known as biofortification to combat malnutrition (Bouis and Welch, 2010: Bouis and Saltzman 2016). In groundnut, apart from reducing aflatoxin contamination, there are efforts also to improve the oil quality by increasing oleic acid and decreasing the contents of linoleic and palmitic acids (Pandey et al., 2016).

For soil nutrition, the varying, but heritable ability to acquire phosphorus from phosphorus-limiting environments in common bean genotypes (Yan *et al.*, 1995) has been used to develop common bean cultivars suitable for phosphorus deficient locations. Cross-pollinated legumes such as pigeon pea (*Cajanus cajan* (L.) Millsp.) now have hybrids being promoted in India (Saxena et al., 2013) and tested in Africa (Ojiewo et al., 2017). These hybrids bring several advantages that include uniformity for harvesting and higher yields.

Where variability within the crop species is inadequate, modern breeding has made it possible to use wild relatives of some crops to develop unique genotypes that express desired characteristics that are otherwise found only in the wild relatives. The traits of interest have been mostly pest and disease resistance and have been reported in cowpea, common bean and groundnut (Ojiewo et al., 2017). Furthermore, transgenic pod borer resistant (PBR) cowpea is already approved in Nigeria (ISAAA, 2019) and is under evaluation in several other African countries to provide value to farmers and consumers while reducing the use of agrochemicals in the control of pod-boring pests.

Overall, the recent improvements to legume crops are meant to address challenges in smallholder farmers' low input systems. These improvements however, can only bring benefits to smallholder farmers if farmers can access, use, and adopt the improved cultivars.

An Overview of Seed Systems

A seed system is an ongoing interaction of various components that come together to deliver and make accessible, seed or planting material to specific clientele (Loch and Boyce, 2003). At times the terms seed industry, seed sector and seed value chain may be used to imply a business context, but the terms "seed supply system" and "seed delivery system" are often used as direct synonyms to describe seed systems in the broad sense. It is called a system because there are various institutions, networks and processes involved, but they all work together to fulfil the goal of making seed accessible to users or farmers.

Selecting part of harvest as seed for subsequent growing seasons is an age-old tradition that has undergone transformation over the centuries to become the present-day organized, and sometimes sophisticated seed industry. Depending on the level of capitalization, seed industries may be characterised by rudimentary technologies or highly complex breeding methods and complementary seed-based technologies. Intensification of the seed industry only started following the development and rapid spread from the United States, of maize hybrids at the beginning of the twentieth century. Modern techniques such as tissue culture techniques and genetic engineering, require more research and capital investments and are responsible for driving growth in the global value of seed business which is now past US$60 billion and is expected to surpass US$74 billion by the end of the year 2020 (https://www.statista.com/statistics/262286/global-seeds-market-value). Despite enormous recent growth, the seed industry has been dichotomous in its structure and organization, pitting informal and formal systems; self-pollinating crops and hybrids; developing countries and developed countries and other distinctions. Today, various models are used to describe the state of modernization of the seed sector and the use of seed technologies (Pray and Ramaswami, 1991; Mabaya et al., 2013), but there is a conspicuous wide gap in seed sector organization between developing countries and the developed countries, possibly due to the history of establishment (Tripp, 2003). In developed countries, the sector started to be organized through mainly small and medium-scale private enterprises and agricultural cooperatives with limited national and international market interests. In the developing countries, the desire to get the seed industry organized first came through the formation of state-owned seed companies and various seed projects (Cromwell et al, 1992; Venkatesan, 1994). Due to its important role in agricultural modernization, economic development and therefore national security, the seed sector is always under public scrutiny.

At global level, the seed sector is governed by a number of instruments, procedures and international agreements such as the International Plant Protection Convention (IPPC), the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), the International Union for the Protection of New Varieties of Plants (UPOV), the International Seed Testing Association (ISTA), the Organisation for Economic Co-operation and Development (OECD) and the Convention on Biological Diversity (CBD). These international instruments, supported by the national laws and policies of signatory countries influence the conduct of all stakeholders to protect interests of farmers and business alike. Application of these guiding principles in entirety or partially has implications on food security, nutrition and incomes, hence governments / public sectors have always been involved in the seed sector to protect both citizenry and investors. Similarly, points of departure on these agreements have become a hotbed for civil society organizations and lobby groups that seek to further influence the exchange of seed. These organizations include La Vía Campesina, Navdanya, Open Source Seed Initiative (OSSI), and the "seed sovereignty" movements (Kloppenburg, 2014; Edelman et al., 2014: Wattnem, 2016). Influenced by pressure groups and development agencies, seed systems have metamorphosed over the years, vacillating between privatization, farmers' rights, globalization and recent corporate consolidations (Bonny, 2017). Up till now, the global discourse on seed systems and, food and nutrition security is often typified by acrimonious contests between extremes: organic farming versus genetically modified (Conway, 2011), subsistence versus commercial cropping and others, instead of deliberate integration of knowledge systems and exchange systems to nurture interaction and collaboration.

In general, seed systems often fall into two broad types: formal and informal, and the longstanding debate has been on which one is better. This paper will present the two systems in terms of efficiencies, but will not focus on the differences between the two.

Informal Seed Systems

Informal seed systems are those in which farmers use all other channels to accessing planting material except certified seed. The use of the term 'informal' has been challenged in recent times; the terms "local" or "farmer managed" seed systems are preferred instead (Walker, 1980; Louwaars, 1994; Venkatesan, 1994; Almekinders and Louwaars, 2002; AFSA, 2017). In the informal seed sector, the farmers provide each other with planting material, either directly or via markets (Venkatesan, 1994). The planting material may not necessarily qualify as seed in a strict formal sense as there is no compulsory quality assurance and monitoring system. In such systems, seed production activities are often integrated into commodity production in a locally organized manner, often driven by timeless indefinable incentives such as cultural norms and traditions. Farmers themselves produce, disseminate, and access seed through three main channels: (i) directly from their own harvest; (ii) exchange and barter among friends, neighbours, and relatives; and (iii) through local grain markets (Sperling and Cooper, 2004). Each channel brings with it variation in purity, physical and physiological qualities (Almekinders and Louwaars, 1999) and its own advantages and disadvantages. Seed in the informal sector may be selected and cleaned manually (Longley et al., 2001), but is otherwise often untreated and thus it is a potential carrier of diseases. Local and distant markets are often important sources of seed to rejuvenate deteriorating stocks or introduce completely new materials (Sperling and McGuire, 2010). While they play a role in seed supply, informal seed systems tend to be maligned and neglected by policies and laws, due to lack of structured governance.

Formal Seed Systems

The formal seed system can simply be described as a purposefully constructed system that involves a chain of activities leading to certified seed of recognized and registered varieties (Louwaars, 1994) through recognition of different seed classes (Table 1). It is a system of seed production comprising regular formal release of varieties, organised multiplication and marketing, a legal framework providing an enabling environment and a functional regulatory authority to oversee the actions of all the system actors (Venkatesan, 1994). The basic tenets in the formal system are to maintain varietal identity and purity and to produce seed of optimal physical, physiological and sanitary quality through a seed certification scheme (Organisation for Economic Development and Co-operation (OECD), 2015). The purpose of a seed certification scheme is to maintain and make available to the public, through the certification process, high quality seed.

Unlike the informal system, the central premise of the formal system is the clear distinction between "seed" and "grain" and clear roles of actors (Jaffee and Srivastava, 1994). The formal seed system is characterized by investments in three main components: public and private research for generation of cultivars and other seed technologies; infrastructure such as seed testing / seed conditioning equipment; seed distribution and retail networks and a cross-cutting quality assurance system. For the three components of the formal sector to deliver, a strong, well-organized seed industry and a seed certification scheme are critical. Formal seed systems are driven by return on investment. Being aligned to various agreements and regulations, formal seed systems serve the dominant organizational and institutional systems in the seed sector; in fact, they are highly regarded and considered the only source of seed that meets the official definition standards.

Table 1. Seed classes recognized for grain legumes (and other crops)

OECD[1]	**AOSCA**[2]	**Produced from**
Pre-basic seed	Breeder Seed	Breeder seed
Basic Seed	Foundation Seed	Breeder or Pre-basic seed
Certified seed, 1st Generation	Registered seed	Basic seed or higher class
Certified seed, 2nd Generation	Certified seed	Certified 1 or higher class

1. OECD = Organisation for Economic Cooperation and Development.
2 AOSCA = Association of Official Seed Certifying Agencies
(Southern Africa Development Community (SADC), 2008; (Alliance for Commodity Trade in Eastern and Southern Africa (ACTESA), 2014)

In addition to the seed classes above, quality declared seed (QDS) is emerging as a fairly new, but popular class of seed, especially for legumes, in a growing number of developing countries. With less rigorous standards than the OECD schemes (FAO, 2006), QDS can be produced under special conditions not only to avert crises, but also as a mechanism to give farmers wider access to new varieties for which certified seed might not be available. The acceptance and recognition of QDS is at different levels across the world, but countries such as Ecuador, Ethiopia, Tanzania, Uganda, Peru and Zambia have since domesticated QDS schemes to enhance legume seed supply.

Production of these seed classes requires careful planning and has an important bearing on the availability of seed to farmers. While certified seed and QDS are the classes that are meant for use by farmers for crop production, their availability is determined by the classes above them as seed flow is unidirectional.

Perspectives on Grain Legume Seed Systems

For decades now, limited availability of good quality grain legume seed has been cited as the major limitation to increasing productivity. It was anticipated that ending government monopoly in the production and distribution of seed through parastatals (Venkatesan, 1994) would diminish informal seed (Louwaars and de Boef, 2012) and improve access to certified seed. Indeed, privatisation of seed sectors brought formal seed systems and ostensible success of private sector seed production and delivery to the fore, but that was, and still is limited only to a few crops that exclude most grain legumes. Instead, successful privatization of national seed sectors has been synonymous with the intensification of the maize hybrid seed subsector. For instance, since liberalization of the seed sectors in Kenya and Zambia, the total number of cultivars released for other staples such as sorghum, common bean and cassava are still less than 30% of the maize cultivars (Das et al., 2019). Correspondingly, the emerging seed companies in SSA also focus on the production and marketing maize hybrid seed (Mabaya, et al., 2013; Das et al, 2019) as smallholder farmers become aware of the need to purchase new hybrid seed every planting season to avoid 19-46% yield losses associated with retaining hybrid seed (MacRobert, 2009).

In contrast to maize and other hybrids, most legumes are highly self-pollinating crops; farmers can therefore re-plant farm-saved seed (Maredia et al., 1999) for several seasons without remarkable yield losses. Hybrid seed business and other high value seeds that offer frequent repeated sales are more lucrative compared to the legume seed business; therefore it is not surprising that the latter is neglected. Also, high seed rates and low multiplication rates mean legumes seed is costly to handle and transport, especially given that the seed users are often scattered and much differentiated. The fact that the cultivars are differentiated and one cultivar cannot be easily substituted for the other makes the accurate prediction of seed demand nearly impossible.

Organization and Structure of Grain Legume Seed Systems

To understand how grain legume seed systems operate, there is a need to give a brief overview of the structure and function. As highlighted earlier, seed systems have three main components as summarized below.

i. **Agricultural Research**: Both public and private institutions conduct research and develop new grain legume cultivars and complementary technologies to overcome current challenges in order to enhance productivity, household nutrition and resilience to climate stress (Buruchara et al., 2011). The Consultative Group on International Agricultural Research (CGIAR) centres; International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Center for Tropical Agriculture (CIAT), International Institute of Tropical Agriculture (IITA) and International Center for Agricultural Research in the Dry Areas (ICARDA), working with the national agricultural research systems (NARS) of various countries have been leading the public research on grain legumes. Various seed companies and other private organizations have also been involved in legume research and development. In some countries, where regulatory frameworks allow, the private sector also draws genetic resources and plant breeding activities from the public sector. In Africa, a regional breeding programme based on specific regional needs was instituted by the Pan Africa Bean Research Alliance (PABRA) in 1996. Through the alliance, NARS in partnership with CIAT develop new common bean varieties that meet preferences and needs across 29 African countries. Based on this arrangement, countries participating under PABRA share germplasm and variety evaluation data which accelerate the release process, often leading to the multiple country releases for some genotypes. A similar regional setup also exists for other grain legumes such as cowpea, chickpea and pigeon pea. In this regard, several farmer-preferred legume varieties with good adaptation and consumer preferred traits have been released in more than one country (Monyo and Varshney, 2016), mostly as direct introductions contributing to increased productivity. While modern genetic and genomic tools have been used to develop new grain legume varieties, it is worthy highlighting that farmers are heavily involved in evaluation process through farmer participatory variety evaluation and selections (FPVS).

While private entities have also developed and released varieties in some countries, it has been mostly been the responsibility of public sector institutions. Public varieties therefore dominate the number of varieties released in most SSA countries. South Africa and Zimbabwe (Figure 1) are exceptions with 69 percent and 54 percent respectively of bean varieties on the 2014 national list developed privately. In contrast, in Zambia, 75 percent of the common bean varieties released between 1970 and 2013 were developed by public institutions, while in Mozambique and Rwanda 100 percent of the varieties on the 2013 variety lists were public.

An interesting feature in grain legumes research is the formal release of some popular traditional varieties. In a number of countries in SSA, "local" bean varieties have been released by the national research programs. These include "Kolta" in Rwanda and "Kablanketi" in Zambia. While keeping the genetic make-up intact, the effort is only meant to improve the quality of planting materials for local varieties normally supplied through farmer groups. It is not yet known how these formally released varieties will be handled in the face of private sector interest in future.

While research is an important component of seed systems, it is worth noting that access and quality of seed are often determined by the efficiency of the regulation and marketing systems.

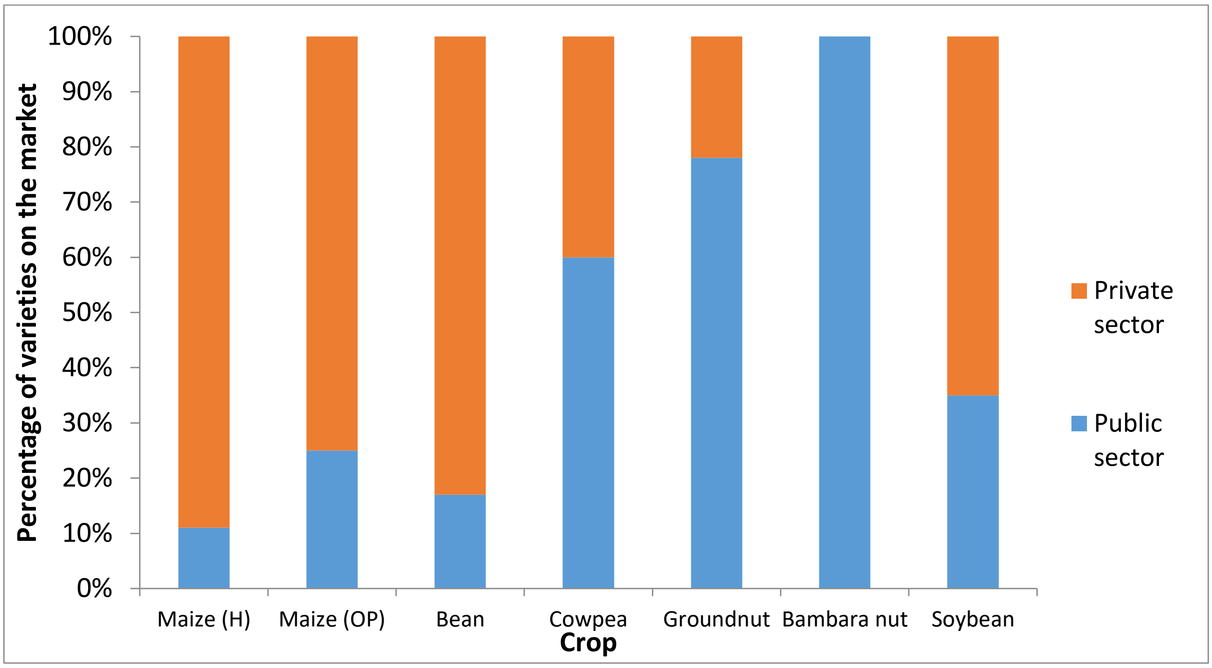

Figure 1: The relative investment of public and private sector in variety development: the case of percentage of public and private varieties of selected crops in Zimbabwe (National Variety List, 2010)

ii. **Control and Policy:** Design and operationalisation of both the regulatory framework and the seed multiplication schemes have far reaching consequences on access to legume seed. Grain legumes are tradable, hence their seeds are subject to regulation according to the Organization for Economic Development and Co-operation (OECD) Schemes for the Varietal Certification or the Control of Seed Moving in International Trade (OECD Schemes in short) (OECD), 2015). Most countries have seed regulatory authorities that are responsible for cultivar testing and release, seed inspection and certification according to standards provided for by the regulations, laws and policies at the national level. In many developing countries, seed regulation and certification is carried out by government departments or specialised units within the NARS. This has been a cause of concern in terms of service delivery and conflict of interest. It is therefore not surprising that one major objective of harmonisation of seed laws and regulations across SSA is to make seed regulatory authorities autonomous to ensure objectivity, efficiency and sustainability (SADC 2008; (Alliance for Commodity Trade in Eastern and Southern Africa (ACTESA), 2014). A number of donor-funded projects increase the NARS' capacity evaluate numerous varieties over short periods of time in many countries, but release process is often frustrated by the failure of the variety release committees to meet regularly for timely release of varieties. For grain legumes, policies have enabled the production and marketing of seed through seed fairs organized at various administrative levels, but commonly at sub district level. Some countries have in recent years outlawed seed fairs for being against policies on agricultural modernization by "promoting counterfeit seed" because the seeds at seed fairs are often not certified. In Malawi, for instance, the government advocated for replacement of seed fairs with private sector-led market exhibitions.

iii. **Seed Multiplication and Marketing:** Public and private institutions, and individuals (or groups) are involved in the promotion and distribution of grain legume seed materials. This segment of the seed system faces numerous constraints. First, there is a need for licensing agreements between originators of a variety and those wishing to produce and market the seed. The grain legume seed market is dominated by publically developed varieties, therefore licensing agreements that enable the private sector to promote public varieties are critical, especially for emerging private seed companies that have no capacity to perform their own breeding research. The licensing may be exclusive or non-exclusive. In countries where Plant Breeders' Rights (PBR) apply, private seed companies may market public varieties and pay royalties to the public breeding institutions based on volumes of certified seed sold. In countries with no PBR, varieties may be available *gratis*. On the other hand, non-exclusive rights present a challenge in the sense that pioneering private seed companies may hesitate investing in promotion dreading that others would ride on its promotion efforts. This tends to limit awareness creation on public varieties resulting in reduced demand and use of new grain legume varieties. Only a few grain legume varieties may therefore be traded on the seed and commodity market despite prolific releases by public institutions. For instance, in SSA it is only in South Africa where common bean varieties developed by the public institution, Agricultural Research Council (ARC) are exclusively licensed to Dry Bean Producers Organization through the private seed company Dry Bean Seeds. Elsewhere legume varieties remain in the public domain for all stakeholders, and therefore face the "tragedy of the commons" highlighted above.

The second constraint in grain legume seed production and marketing is the production of early generation seed (EGS); breeders', pre-basic and basic seed which has a bottleneck effect on the subsequent seed classes. Overcoming the EGS challenge (Le Page and Boettiger, 2013; ISSD, 2013; Lion et al., 2016) requires transformation of the legume seed systems. The legumes subsector is dominated by public varieties, therefore early generation seed production is carried out by plant breeders from NARS. In Mozambique and Rwanda special basic seed production units exist within the NARS. In Tanzania, the Agricultural Seed Authority (ASA) is a parastatal that was established to undertake all basic seed production. The required parent seed and the land area for EGS production is enormous given the low multiplication factor for grain legumes. These requirements are often beyond the reach of the resource-constrained NARS and as a result, there is always a huge deficit between EGS production and certified seed requirement. It has however been argued that the stringent adherence to these classes is the main cause of limited availability of certified seed due to low multiplication factor for some legumes.

Third, access to and use of legume seeds are also constrained by the distribution network. Seed retail outlets may be owned by seed companies or independent, but contracted. Also, seed marketers are accredited by the seed authorities and receive special licenses for trading in the different classes of seed. In some countries, certified seeds of all crops are produced by government controlled parastatals or departments. These public institutions operate in limited regions of the countries (World Bank, 2012), creating seed supply bottlenecks. In countries where basic seed production is decentralized, seed companies, farmer groups, and cooperatives can produce basic seed, but only as growers for accredited seed companies.

The Rise of Pluralistic Grain Legume Seed Systems

Unlike in developed countries where commercial agriculture drives the seed sector, legume seed production in developing countries remains erratic due to the subsistence nature of production from where only a little surplus is marketed (Bishaw et al., 2008). As a result, formal legume seed systems have often remained undeveloped or ineffective for variety dissemination. David and Sperling (1999) concluded that the sole use of the formal common bean seed systems would delay the wide dissemination of newly released varieties in SSA. Formal grain legume seed systems in developing countries are therefore faced with a myriad of challenges that include: i) supply to meet the ever fluctuating and differentiated varietal demand, ii) increasing need for targeted information/ knowledge on newly released varieties and complementary production technologies, and iii) responsiveness to shorten lag period variety release and use.

Neglect by the private seed companies may have strengthened the informal seed system and the role of farmers in seed supply for legumes, but informal seed systems are often much localised, specific and their quantity and quality of seed is often questionable. Sole reliance on farmer-to-farmer seed distribution may, similar to formal systems, also delay the full impact of new cultivars. Seed delivery systems that integrate strengths from both formal and informal systems have been developed, harnessing the power of farmers' knowledge through participatory variety selection and tapping pre-basic seed from the formal sector. In fact, the distinction between formal and informal seed systems is weakening in legumes; there is cross-strengthening between the systems and numerous organisations produce unregistered, unlabelled and uncertified seed (Sperling et al., 2013).

Numerous legume seed dissemination models have emerged over the years, varying from strict formal systems to various nuances of rudimentary informal / farmer-led models. Some of these models also embrace farmers as both producers and users of seed (Table 2), and these have been commonly called "integrated" or "pluralistic" seed systems. Interestingly, others take a business approach with sustainability and profitability being central (Bishaw et al., 2008). For instance, ICARDA promotes establishment of village-based seed enterprises (VBSE) to produce and market quality seed in remote locations that are not covered by the formal sector (Bishaw and van Gastel, 2008). The Integrated Seed Sector Development (ISSD) project promotes a similar model called local seed business enterprises (Kansiime and Mastenbroek, 2016). These models are viewed as semi-formal or intermediate. Hanif and Sperling (2017) identified seven pathways or models that are currently delivering legume seed to smallholder farmers in developing countries. These are commodity traders, community-based seed producers, agrodealers / agro-input shops, village based advisors (also called private service providers), seed company agents, supply-chain facilitated access and integrated service through social enterprise. The models have varying degrees of inclination towards commercial and social intends, and their use depends on socio-economic context and importantly on the rationale for seeking seed. For instance a farmer seeking to test latest cultivars may approach company agents while another may approach community-based seed producers for traditional varieties. It is therefore prudent to understand how each model can be assessed and understand the drivers of farmers' choice so that they can be served more effectively.

Table 1. Integrated seed system actors and their complementary roles.

Actors	Roles and responsibility
NARS	Variety development; production of breeder/pre-basic/basic seed; provision of information on new varieties; support for seed production skills enhancement
Seed Regulatory Authorities	Inspect and certify basic and certified seed to ensure the supply of quality seed to the market; train seed companies on quality seed production and of the rules and regulations governing bean seed production
Seed Parastatals/ Seed Companies	Facilitation of variety testing; seed multiplication of preferred and released variety; marketing of certified seed of popular varieties; provision of business opportunities and capacity building for contracting out-growers; provision of initial seed for bulking
Local Extension Services: (Government / Non-governmental / Community based / Farmer organisations)	Decentralised testing of varieties; decentralised seed production; popularisation of preferred varieties; community mobilisation; capacity building for local seed supply systems; development and dissemination of information, education and communication (IEC) materials including translation of technical manuals into understandable languages

Farmers seed producers/entrepreneurs	Local seed production and supply/marketing of locally preferred genotypes; creating farmer awareness; popularisation of preferred varieties in joint demonstrations and field days with NARS and seed companies; training of other farmers in bean agronomy and post-harvest management/farmer implements
Farmers (individual/groups)	Testing and promoting varieties; grain production to drive seed supply.
Local grain traders	Linking local seed producers with wider grain legume seed markets, and moving varieties beyond local zones; provision of grain market intelligence
CGIAR/ Development Partners	Provision of promising elite germplasm to NARS; co-research key bottleneck areas; evaluate bean seed delivery systems and build capacities in seed management/ business skills; support monitoring and evaluation

Adapted from Rubyogo et al. (2010)

MEASURING SEED SYSTEM EFFICIENCY

The Principle of Efficiency in Systems

Efficiency and effectiveness are often used as dimensions of performance in product development processes. In general, efficiency refers to the best use of resources in the production of a given product or service, and compares results with expectations or targets. Usually, there are two types of efficiency: technical efficiency which focuses on minimizing input use for a given level of outputs thereby lowering expenditure and allocative efficiency which explores combining different resources to produce various and competing system outcomes (Worthington and Dollery, 2000: International Transport Forum, 2008). Technical efficiency which targets minimum possible cost, is measured as the ratio between what is actually produced and the maximum achievable output. Technical efficiency may be input-oriented or output-oriented, focusing on minimizing inputs for a specified output in the former and maximizing the output in the latter. Inefficiency in contrast, would be demonstrated when resources or inputs are left idle or not producing the desired outcomes in the best possible way.

From a seed systems perspective, the term efficient is at times used as a dependent variable or an incomplete concept, such as a ratio of one input factor to one output factor. The first query on assessing seed systems efficiency relates to their complexity. Seed systems are complex because they: are heterogeneous and dynamic, operate at different geographic levels, and consist of various interrelated systems. Seed systems are characteristically affected by various sources of complexity that affect supply chains. These include network, process, customer and information complexities (Christopher, 2011), which in turn affect the relevance of seed systems, hence the availability, affordability and suitability of the seeds supplied. A thorough singular and combined analysis of these factors is therefore essential to establish seed system efficiency.

Another question would be to determine the type of efficiency most relevant to seed systems. Assessing efficiency in seed systems is therefore, not a straightforward task. Elsewhere, in highway management, efficiency has been enhanced by simply doing the "right things" (Choi and Jung, 2017), but these need to identified foremost in relation to the objective of seed systems, which is to ensure farmers access and use quality seed of varieties of their choice for betterment of livelihoods.

Second, efficiency in the context of seed systems has to be well defined. The varying definitions suggest that there is a strong element of subjectivity in the definition of efficient seed systems. Elsewhere, it has been observed that conflicting objectives about what a system is meant to achieve and boundaries of the system bring challenges to measuring efficiency (Canadian Institute for Health Information (CIHI), 2012). While all seed systems aim to avail seeds of choice to farmers, efficient seed systems have the diversity of plant material required by the users in terms of quality, quantity and type (Loch and Boyce, 2003; AFSA 2017). Farmers are a heterogeneous and dynamic group; their constantly changing and differentiated needs correspondingly require responsive and efficient seed supply systems.

In addition to appropriateness and diversity of cultivars, timeliness of seed supply and affordability (Monyo et al., 2004) are other elements of efficient seed systems. Poor timing, especially delayed supply of seed and other agricultural inputs has often been cited as a constraint to raising productivity in agriculture. The major bottleneck has been the bureaucracy in the distribution network. Efficient seed systems should therefore combine formal, informal, market and non-market channels (Maredia et al., 1999) to overcome these distribution-related challenges to stimulate and satisfy farmers' seed demands. From an economic viewpoint, efficient seed systems should be sustainable over the long term. In fact, some authors (Loch and Boyce, 2003) propose that seed programs that supply free or subsidized seed should be excluded from discussions on seed systems due to their use of external resources and the absence of in-built incentives. It has been noted that poorly designed seed aid can create a dependency on repeated aid thereby weakening coping strategies and resilience (McGuire and Sperling, 2013). From the foregoing, it is clear that efficiency of seed systems is built on various elements that need further definition into outputs and outcomes.

Third, identifying and applying right metrics and to measure performance is critical for identifying improvement areas in seed systems. There are many indicators that could be used to measure performance, but the use of key performance indicators (Christopher, 2011) is critical for balanced metrics. Elsewhere, it has been noted that measuring intermediate outputs and outcomes is critical in measuring system-level efficiency (CIHI, 2012). Understanding methodology for measurement and collecting the data is equally important. On one hand, formal seed systems being commercially-driven and seeking maximization of return on research and development investment, may have records to capture the metrics. On the other hand, informal systems, driven by timeless cultural norms and other intangible incentives, may have incomplete or no records at all. Finding a performance measurement framework that fairly assesses these two divergent systems therefore presents a challenge. It is also debatable whether, the Pareto efficient frontiers should be used to evaluate aggregate efficiencies (Golany et al., 2006) for the various sub-systems, and the seemingly competing informal and formal seed systems. Typically seed flows from research to distributors and users, hence seed systems are vertically integrated and therefore, require that aggregate efficiencies be combined.

Current Estimations of Seed System Efficiency

A number of frameworks were developed in the 1990s with the support of the CGIAR programmes (Pray and Ramaswami, 1991), the Overseas Development Institute (ODI) (Cromwell et al., 1992) World Bank (Jaffee and Srivastava, 1994; Venkatesan, 1994) to gain an understanding of progress and gaps in seed systems in developing countries. These various attempts to assess the performance efficiency of seed systems only produced aggregate indicators for instance at research and development level, policy level and seed distribution level instead of being holistic. This points to the notion that the interest had been to review the structure, conduct and organization of seed systems and not the efficiency *per se*.

For a long time, seed quantities produced were used as a proxy for the performance of seed systems, but from the implied definitions of efficient seed systems above, it is clear that more information is required. Parameters such as the quality of seed, quantity sold per variety, selling prices, the socio-economic data of the purchasers and the impact (Spielman and Kennedy, 2016) are also necessary. It is however, very rare to get a full assessment of all the elements.

According to (Spielman and Kennedy, 2016), the real attempts to measure industry performance were from the projects from the CGIAR; Diffusion and Impact of Improved Varieties in Africa (DIIVA) in 2014 and Tracking Improved Varieties in South Asia (TRIVSA) in 2015. Both DIIVA and TRIVSA had data on institutional strengths, innovation and the relative spread of varieties, albeit a focus on public research institutions only, yet the private sector played a key role as well in variety dissemination. This incomplete analysis brings bias into the assessment. The World Bank, working with seven national statistical agencies also developed a tool for collecting agricultural data, which indirectly measures the seed sector performance. This tool, called the Living Standards Measurement Study-Integrated Surveys on

Agriculture (LSMS-ISA), can generate georeferenced data on varieties accessed and seed prices (World Bank 2015). While DIIVA, TRIVSA and LSMS-ISA can generate temporal and spatial data on variety adoption and use, the down side is that the three do not capture seed quality neither do they give a unitary measure of efficiency. Improving on DIIVA, TRIVSA and LSMS-ISA, Spielman and Kennedy (2016), proposed a holistic set indicators covering various domains of the seed sector including performance, structure, innovation regulation and intellectual property rights and biosafety. While this proposed list of indicators captures both formal and informal systems, it does not have a scoring system nor a unitary measure of efficiency. Meanwhile, a number of indices listed below have also been developed to assess the performance of seed systems.

- **Enabling Business in Agriculture/Seed component/World Bank (EBA/WB)** – This has a global context, but with a focus on monitoring legal and regulatory issues to improve business performance. This Index is not just about seed sector, but improving the enabling environment for agriculture more broadly. The aim is to inform national and regional planning and policy making.
- **Access to Seeds Index/Access to Seeds Foundation (ATSI/ASF)** – Has global context, but also has an East African Regional component. The focus is on the private sector – seeking to improve access to quality seed.
- **The African Seeds Access Index (TASAI)/Cornell University and Market Matters Inc.** The focus is Africa-specific and is 100% about seed and the seed sector. It looks specifically at seed sector performance at country level, from the enabling environment to 20 specific indicators in the formal seed sector (www.tasai.org)
- **Agrobiodiversity Index / Bioversity (ABDI)**

  This index has a global focus on agro-biodiversity in farming systems; seed is only about one quarter of the focus. (Bioversity International, 2019)

- **Seed Sector Assessments**

  Wageningen University Research carried assessments to give an overview of country seed sector structure and organization during the establishment of the Integrated Seed Sector Development (ISSD) project (www.ISSDseed.org)

The indices above were developed with different perspectives; they still expose the distinction between formal and informal systems, suggesting the need for an alternative framework that can adequately capture indicators from both systems. The Access to Seeds Index is a framework that comes close to estimating the ease with which farmers acquire seed, but it focuses on the commercial sector and only on the leading seed companies. The ABDI, by considering diversity, it covers seed access from both informal and formal seed systems, but does not capture one important element, seed quality. It is therefore critical to design a framework that covers various elements of efficient seed systems discussed earlier in this paper and apportion weights depending on the perceived importance.

Proposed Metrics for Determining Grain Legume Seed System Efficiency

For determining efficiency, seed systems will be assessed on four main criteria: access, quality, sustainability, and conservation and use of genetic diversity. Selection of these parameters was based on the definition and objectives of seed systems, with a particular emphasis on seed security. According to FAO (2016b), seed security exists when there is "… sufficient access to adequate quantities of good quality seed and planting materials of preferred crop varieties at all times following both good and bad cropping seasons." While this definition is user-oriented, various considerations were made to define indicators that are appropriate for both seed suppliers and seed users. Also, an effort was made to include both process/ performance indicators such as outputs and impact indicators that capture spatial, temporal and demographic differences. Overall, the author decided to use indicators that can be expressed in relative rather than absolute numbers to ease the process of scoring. This also helps identify how the metrics can be easily measured and described using appropriate comparatives such as better, faster, cheaper (Christopher, 2011).

Seed Access

According to FAO (2016b), seed access is defined by two main elements; ability and willingness, to acquire seed through a given option. Access has several dimensions that will be explained below. The first dimension of access should involve the availability of seed. This gives the quantity of seed produced or distributed, and the location. The volume of seed produced give an indication of the ability to respond (Christopher, 2011), while the supplied volume shows the actual responsiveness. Rather than absolute seed production or supply volumes, it may be relevant for the purposes of measuring seed system efficiency, to have the data expressed as percentages of the seed volume required to plant the total crop area. For instance, in Tanzania, common bean certified seed production was reported to meet only 2% of the national seed requirement (ASARECA and KIT, 2014), and that easily gives a hint on the performance of the sector.

Furthermore, certified seed marketing and distribution is often through a few officially recognized seed outlets and with limited spatial reach. For instance, Rohrbach et al, (2001) and World Bank (2006) reported absence of seeds shops in 47 out of 128 districts in Mozambique and an average ratio of one seeds shop to 40,000 smallholder farmers. The situation may have improved, but many developing countries still have poor supply networks due to low density and poor quality of road infrastructure (Townsend, 1999), especially in rural areas. In contrast, farmers' seed systems are ubiquitous and that ensures rapid spread from the source to users. The use of farmer groups and other informal channels have been reported to hasten legume variety dissemination Malawi and Tanzania (Rubyogo et al., 2007; Maereka and Rubyogo, 2015), and West Africa and South Asia (Rubyogo et al., 2019). Similarly, Asare-Marfo et al. (2016) reported that 50 % of high iron bean farmers interviewed in Rwanda had acquired seed through farmer-to-farmer social networks.

The second dimension of access is the amount of seed acquired or planted. This helps to exclude seed that is produced but carried over to future planting seasons. This information may however, not be readily available in informal systems. It is estimated that informal seed systems contribute more approximately 90 % of the legume seed planted in developing countries (McGuire and Sperling, 2016), but there is great variability among countries.

The third dimension of access is affordability. Where the few seeds shops exist, another major limitation to access to seed under the formal sector is the fact that certified seed is often purchased strictly on cash, which smallholder farmers may not always have, and credit is rarely available (Adjognon et al., 2017). Seed affordability is another impediment to the use of improved legume varieties. Affordability may be a very difficult indicator to measure, but the ratio between prevailing seed price and grain price may be important. On average grain sales at about US$0.30-0.40 per kg while certified legume seed may be sold on the formal market between US$2 and US$3 per kilogram, which is deemed expensive for most smallholder farmers in Africa. Seed price to grain price ratios affect the breakeven yields required to recover the cost of seed (Mac Robert, 2009), and therefore become an important guide on farmers' willingness to invest in seed purchase compared to possible alternatives such as using their own grain stocks for "seed".

Another interesting feature that influences seed affordability is the appropriateness of packaging. In farmers' seed systems, seed may not be prepacked; customers may bring their own "package" and decide how much seed they want exactly. Borrowing from the developed countries, the formal sector in developing countries was viewed as a platform meant only for large scale commercial farmers requiring large volumes of seed. The traditional seed package size in the formal sector was therefore meant to establish at least half or a hectare for most staple crops. For instance, in Tanzania, ASA distributed bean seed in 25 kg and 50 kg packs (Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) and Royal Tropical Institute (KIT), 2014), while maize was commonly sold in 25kg packs. These pack sizes were unsuitable for smallholder farmers, whose landholding size may be as little as a tenth of a hectare and could not afford a once-off purchase of these huge packs. To make seed affordable to a wider group of farmers, and following trends in other consumer goods such and basic commodities, seed companies were encouraged to supply smaller seed packets. Many seed companies now supply seed in 1, 2, 5, and 10 kg-packs as standard and tailor-make 200 and 500 gram packets for specific markets and free samples for farmers' evaluation (Bigirwa and Kapran, 2017).

Meanwhile, the small-pack approach has been considered successful at reaching smallholder farmers through both seed companies and community producers of QDS for legumes in SSA and south Asia (Rubyogo, et al., 2019). The approach however, is questionable in two main aspects. First, the sustainability of the approach given cost implication for seed processors; this will be discussed later in the paper. Second, the impact of a small seed pack for instance 100g-pack, at individual farmer's level needs further scrutiny. It is otherwise deemed "a *brutum fulmen"* (very superficial) to reach out to many farmers, without addressing the food security and poverty reduction outcomes intended.

This gives rise to yet another dimension of access, which is farmer development or profitability. Given these arguments, it would therefore be prudent to have seed access data that includes the total amount of seed produced and sold or distributed, percentage of area planted with the seed, socio-economic status of the farmers before and after accessing the seed.

Seed System Sustainability

Seed systems have to be sustainable over the long term as discussed earlier. Discussions on sustainability of supply chains often revolve around the triple bottom-line and 3Ps; people, planet and profit (Christopher, 2011). Both suppliers and users of seed need to realize benefits to continue engaging each other; in-built incentives provide the best drive for both in a “win-win” situation. In agricultural systems, sustainability is affected by both biological and physical attributes of the system (Herdt and Lyman, 1991). The author therefore proposes three dimensions of sustainability. First, profitability is the major benefit. While profitability is the pinnacle of commercial formal seed systems, especially from the supply side, it cannot always be quantified for farmers’ seed systems. Several authors have described different models of profitable and sustainable farmer-based seed enterprises (Sahlu et al., 2008; Kugbei and Bishaw, 2002; Louwaars and de Boef, 2011; Kansiime and Mastenbroek 2016), but often not for long, unless they transform into fully commercial enterprises. The length of time in operation can be misleading in this case; for instance, long term operation for free seed distribution programmes does not imply sustainability. One major finding of a community seed production (CSP) workshop organised by FAO and ICRISAT based on case studies from Africa, Asia and Latin America was that sustainability of CSP was very sporadic and site-specific; success factors are often variable (Ojiewo et al., 2015). Meanwhile, countries such as Ethiopia and India, present a conducive environment for CSP through larger cooperative structures that address limitations such as capacity gaps in quality control, marketing skills and business management skills, and a limited market. Where the market is huge, there is always some of external support. For instance, in Ethiopia CSP is driven by navy bean export (Tumsa et al., 2015), but there is government support in the navy bean value chain.

Second, sustainability can be assessed in the context of resilience. Informal seed systems are widely viewed as resilient. Following the sudden economic downturn in Zimbabwe, informal seed systems (Mutonodzo-Davies, 2010) supplied over 95% of the seed sown for some dryland cereals and legumes. Similarly, informal legume seed systems are promoted in post-disaster situations in many countries as part of transition from aid to sustainable development (Sperling et al., 2004).

The third element of sustainability is advisory links. Nowadays, supply chains have generally moved to information systems rather than focusing on keeping inventories (Christopher, 2011). Similarly, in seed systems, farmers need information to make decisions on technologies and to link with other segment of the seed systems such as formal institutions (McGuire and Sperling, 2013), grain market agents, extension services and information services. The move from centralized to decentralised seed production and distribution requires information, especially at local level.

To assess sustainability of seed systems, one needs to consider the gross margins for both suppliers and users of seed, the partnerships involved therein and the ability to overcome socio-economic shocks.

Seed Quality

Both seed suppliers and seed users are concerned about seed quality – genetic, health and physiological quality. The user desires and deserves varietal purity and, uniform and healthy establishment in the field, while the supplier must meet these needs to build reputation. In the formal seed sector, quality is achieved through adherence to standardized seed production practices and can be verified by field inspection and post-harvest sampling and testing of seed in the laboratory (OECD, 2015). While the formal seed sector is designed to satisfy that, attaining perfection is somewhat elusive due to a number of reasons including under-capitalization in developing countries (van Gastel et al., 2002); reports of counterfeit seed abound (AGRA, 2011: Joughin, 2014), albeit not only in legumes.

On the other hand, due to the absence of a quality assurance system in the informal sector, seed may be minimally processed manually (Longley et al., 2001), and often untreated and therefore may potentially spread diseases and pests. To highlight this challenge, recent studies across several states in India reported that rice, wheat, soybean, chickpea seed from farmers' systems fell below the minimum seed certification standards in terms of germination, pest damage and disease presence (Singh and Agrawal, 2018).

Also, there is no variety verification in informal seed systems. In fact, identification of newly introduced varieties is often complicated in most informal systems, especially where farmers use physical characteristics such as grain colour (or its pattern), grain shape maturity period or growth habit as the main varietal identifier. One variety may therefore carry several names across communities or conversely, many varieties (and even of different crops) may be known by a single name. Poor or complex and inconsistent relationships between molecular markers, variety names and agro-morphological traits have been reported in traditional varieties of sorghum in Mali (Chakauya et al., 2006), cassava in Uganda (Kizito et al., 2007), and sorghum in Zimbabwe (Mujaju et al., 2003; Mujaju and Chakauya, 2008). In other instances, varieties are named after the agents that introduce them, further contributing to loss of original identity of varieties. Due to these and other inconsistencies, there is always suspicion that farmers' seeds are of inferior quality. Some studies, however have shown that farmer seed systems may supply seed within the acceptable quality standards of germination (Bishaw et al., 2012; Kusena et al., 2017) and freedom from some economically important seed pathogens (Kusena et al., 2017).

In addition to varietal purity, appropriateness of the varieties supplied by a system is another important dimension of quality. Appropriateness includes adaptability to the growing environment and other desirable characteristics demanded by farmers. Measuring this may present a challenge, but a proxy can be used. In principle, new varieties are supposed to better than existing varieties, hence it can be assumed that by farmers may be better off by accessing new varieties. Similar to other supply chains where product lifecycles that have become short (Christopher, 2011), speed is also of essence in seed systems as farmers continue to pursue better and higher yielding varieties with other attributes demanded by increasingly knowledgeable consumers. It will therefore be prudent to have a measure of variety replacement in the assessment of seed system efficiency, using the age of varieties supplied and planted. Asfaw et al (2013) observed that farmers in Southern Ethiopia grew the same common bean varieties for 10 to 11 years, unlike the 3-4 years experienced in advanced maize seed systems (Das et al., 2019). Turnover rates are generally low for legume varieties. Typical legume varieties that have been on the market for long include "Pendo" and "Lyamungo 90", which are groundnut and common bean varieties, respectively that were officially released in Tanzania in 1990 (30 years on the market to-date) and "Napilira," a common bean variety officially released in Malawi in 1994 (26 years on the market to-date). Low variety turnover is often associated with limited gains in productivity, which in turn, negatively affects profitability of smallholder farmer production systems.

Conservation and use of genetic diversity

It has been observed that climate change brings several and unpredictable challenges to farming communities and there is a close relationship between genetic diversity and resilience, especially under the uncertainty associated with climate change. Legumes have great genetic diversity that makes them adapted to various climates and continents (FAO, 2016a), but for some legumes such as chickpea, some diversity was lost during the domestication process (Abbo et al., 2003). However, several studies have shown that formal seed systems are not able to supply the genetic diversity that farmers need (Jarvis et al., 2011), and that presents adaptation challenges. Though the common bean is believed to still have rich genetic diversity, the formal seed systems have no capacity to supply the diversity of varieties needed by farmer as seed companies may focus only a few varieties. For instance, 2014 data from the Seed Services Unit in Malawi and the Department of Seed Services in Zimbabwe showed that one variety contributed more than 93% of the common bean certified seed supplied in each country, despite prolific release of varieties in the two countries. In the case of soybean, five introductions accounted for 55% of the pedigree in public soybean cultivars in the USA in the 1990s (Gizlice et al., 1994).

Smallholder legume farmers often grow diverse crop varieties and the selections may be based on growth habit, tolerance to stresses, culinary aspects such as taste, flavour and cooking time and other qualities (Coomes et al., 2015). For instance pigeon pea farmers in Malawi and Mozambique prefer a local variety called “Mthawajuni” for its early maturity, while some common bean farmers in Zambia prefer “Solwezi,” and “Lundazi” beans for taste. These local varieties are not available through the formal seed systems and farmers therefore need to look elsewhere for their diversified variety needs. It is therefore critical under this component, to look at the number of varieties supplied by a specific seed system. Furthermore, the number of crops supplied by each seed system or model is equally important because farmers rarely plant a single crop. For instance, studies in Mozambique showed that 50 % of farmers older than 45 years of age grew more than 10 crops in a season (FAO, 2008).

Weighting of Parameters and Indicators

While all the indicators described above are considered important in the evaluation of efficiency of legume seed systems, it is inevitable that some indicators have a more critical role than others – these are called key performance indicators (Christopher, 1998) and they often define failure or success. Selection of the key performance indicators used in this paper was based on a number of factors including relevance, reliability and feasibility. The weights for these indicators are based on their perceived critical contributions to the overall efficiency of a seed system, based on the author's perception from literature. Other seed system practitioners may therefore have a different perspective on the weighting and pairing of indicators and dimensions proposed herein.

From the definition of seed systems, the author considered it critical to apportion more weight to the seed access indicator (Table 3). The access indicator and its various dimensions define the main goal, activities, and relevance of legume seed systems to smallholder legume farmers. Seed access and its dimensions defines the acquisition and use of seed. All the beneficial characteristics of varieties, cannot be expressed if there is no access to, and use of seed of the varieties. For instance, the benefits of biofortification, culinary qualities, yield and others discussed earlier in this paper only come through access to seed. Other indicators, may not have more profound impact on the seed supply landscape than the dimensions of access. Among the dimensions of access, the volume of seed supplied and planted, and the percentage of new varieties have the most weight due to their reflection of all the other dimensions of access. For instance, whether the seed is affordable or not, the area planted with the seed is one indicator that counts the most, especially when the varieties are new. In the United Kingdom, breeding and the use of new winter wheat varieties accounted for 50% of the three-fold increase in productivity between 1947 and 1986 and, for a further 90 % yield increase between 1982 and 2007 (Bruins, 2009).

Table 3: Weighted seed system efficiency parameters and indicators

Seed Supply Model	**Parameter**	**Aggregate Weight**	**Disaggregated weight**	**Indicators**	**Means of verification**
A,B,C etc	Seed Access	0.4	0.1	Volume of seed produced (% of requirement – based on area planted)	National seed authority statistics; Survey, KII and FGD
			0.3	Volume of seed sold / supplied (as % of requirement – based on area planted to the crop)	National seed authority statistics; Survey, KII and FGD
			0.3	% of new varieties (<10 years old)	National seed authority statistics; Survey, KII and FGD
			0.1	% of affordable seed packs (<10kg)	Survey, KII and FGD
			0.2	Grain price to seed price ratio	Survey, KII and FGD
	Seed System Sustainability	0.25	0.1	Reliability and consistency of source of information (including feedback mechanism)	Agricultural extension reports, Survey, KII and FGD
			0.3	Return on investment in seed production or gross margin	Snap survey
			0.3	Return on investment in seed purchase or gross margin	Snap survey
			0.1	% partners involved	Snap survey, agricultural extension reports
			0.2	% seed supplied with external support	Agricultural extension reports, Survey, KII and FGD

	Seed Quality	0.2	0.3	% of varieties accurately identifiable	Survey, key informant interviews (KII) and focus group discussions (FGD)
			0.2	% of seed with standard certification	National seed authority statistics;
			0.2	% of seed with other quality assurance system	Seed producers and users
			0.3	Level of satisfaction	Survey of seed users
	Conservation and Use of Genetic Diversity	0.15	0.6	Number of varieties supplied (% of the required)	Survey, KII and FGD
			0.4	Number of crops supplied (% of the required)	National seed authority statistics; Survey, KII and FGD

In maize, from the four-fold increase in global yield between 1929 and 1990, 75 % was attributed to new varieties, particularly hybrids (Zecchinelli, 2009). Similarly, the Green Revolution in Asia was a result of the widespread access to high yielding varieties albeit through both formal and informal systems (Tripp, 1997). Grain legumes gained only 39 % in productivity over the past 50 years (Belhassen et al., 2019), new varieties therefore may have contributed only about an eighth of phenomenal yield gains reported in wheat. New varieties are therefore key in solving grain legume farmers' age-old challenge, increasing productivity and to meet emerging needs through technologies such as biofortification (Bouis and Welch, 2010), transgenic PBR cowpea (ISAAA, 2019) and others discussed in earlier sections. From the discourse above, the author reasoned that 40 % would appropriately define the proportion of seed system efficiency attributed to seed access.

After access, sustainability was considered the second most important indicator of seed system efficiency. If a seed system cannot consistently supply seed, the benefits highlighted above cannot be realized. The key dimension profitability for both the supplier the use of seed is major driver of sustainability. Furthermore, links between seed supply and other components of the value chain drive the demand for seed. For instance, information is key component of the knowledge cycle; it often triggers the decision to use and adopt new technologies and varieties (Coudel and Tonneau, 2010). Therefore without appropriate links, especially with information systems, the use of desired varieties and other technologies may remain below optimal. While there is no literature to directly suggest weight for sustainability, the author found it appropriate to allocate 25 % of seed systems efficiency to sustainability.

Seed quality is one key element in seed use; all the benefits of seed access including new varieties will not be realised with poor quality seed. For instance, Barnard and Calitz (2011) reported poor stand establishment and low yield due to use of poor quality wheat seed at planting. In addition to physiological quality, legume seed may be less desirable due to the presence of seed-borne or seed transmitted pathogens. According to Singh and Agrawal (2018), the use of good seed quality alone contributes 20 % to 25 % increase in crop productivity in India. Following this example, the seed quality indicator and its dimensions is apportioned 20 % in this paper. The two main dimensions of quality are variety identification and level of satisfaction. The two can be clearly defined in both formal informal systems and summarize the indicator well, despite the latter being very subjective.

The conservation and use of genetic diversity has the least aggregate weight. This indicator, though important, especially under climate change, market imperfections and resource constraints (Lipper et al., 2005), may not be very critical as farmers may successfully grow one variety or only a few varieties that meet their food security or market needs. Also, diversity could also be about choices, not necessarily about need. Under this indicator, diversity at varietal level is considered a more important dimension than crop diversity since the focus is at crop level, in case conditions may limit the supply of a seed to single legume crop.

CONCLUSION AND MOVING FORWARD

The indicators proposed in this paper serve the purpose of measuring seed system efficiency in line with seed system objectives. Literature suggests that using outputs in efficiency measurement is quite appropriate and encourages the overall performance (CIHI, 2012). It is anticipated that the indicators suggested herein can lay the foundation for objective assessment of legume seed systems efficiency. The author had in mind, a "dash-board" type of a rapid decision making tool when it comes to efficiency of legume seed systems. From the foregoing, it is evident that measuring the efficiency of grain legume seed systems is only achievable with adequate, accurate and comprehensible information and analyses. While it is now apparent that some of the information required may not be easily available, especially in non-formal systems, it would be worthy piloting in a case study, the indicators and weights proposed herein to generator a feasibility index. Missing data creates a challenge in assessing efficiency of seed systems and may result in less meaningful, inconclusive or invalid results in the final calculations. It has also been noted that certain indicators are available only at broader geographical coverage than the local seed systems may demand. For this reason, the author highly recommends wide consultations with stakeholders to reach consensus on the indicators and methodology.

Also, there could be data incompatibility among the various seed system models. For instance the levels of satisfaction, non-certified seed quality assessments and returns on investment may have different meanings and subjective in various systems. Practitioners therefore need to be able to capture the metrics associated with efficiency indicators to overcome gaps and inconsistencies in data that are critical for efficiency calculation.

Also, attribution in agriculture is major challenge; understanding the drivers of choices and sustainability need through investigation. There is a need for a mechanism that can trace and verify seed from a given source or system to the farmers' field and thereafter assess the impact attributable to the seed. Modern tools in plant breeding may only help identify the adoption and spread of varieties, but the actual efficiency of the mechanism of spread remains a pipeline dream due to unavailability of information and data.

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