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*Review*

# Integrating crop and livestock in smallholder production systems for food security and poverty reduction in sub-Saharan Africa

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**The resource base that ensures food supply and the socio-economic component which depends on this resource base are the two major components that make up the food system in sub-Saharan Africa. The sequence of the food system is organized in a spatial flow framework of biomass base. The components of rural production system consist of food production biomass at homestead and farm level, and often at the communal base non-food production lands. The degree of integration between these resources base determines flows such as material cycle, energy, food and cash, and influences how the entire production system needs to be managed. The management system influences resource use efficiency and economic returns at different levels, at individual household, communities, and national levels. Efforts to developing agriculture and reducing poverty remained sectoral and focused mainly on a specific crop or individual animal level, failed to see interconnections among sub-systems and across space and time. The concept of the integrated food system has not been adequately adopted, in many sub-Saharan African countries and the agricultural system in the region continues to exhibit a low level of productivity and resource use efficiency. Hence, food insecurity and poverty remained high among smallholder farming communities producing crop and livestock despite the availability of arable land and abundance of another natural resource. This review focuses on the significance of integrated crop-livestock system in the tropics and suggests a framework to begin understanding and addressing complex problems in smallholders' production system.**

**Key words:** Biomass production, food security, crop-livestock systems, poverty, smallholder production systems, sub-Saharan Africa.

## INTRODUCTION

Agriculture is the largest single occupation in the world, employing 40% of the global population and contributing substantially to the health and well-being of rural populations (United Nations, 2015). Approximately, more than 950 million people are found in Africa, with 60% between 15 and 24 years (Koira, 2014). The majority of the population in sub-Saharan Africa (SSA) resides in rural areas, and up to 80% are smallholder farmers (Senbet and Simbanegavi, 2017) directly or indirectly dependent on agriculture for their livelihood. Africa presents a paradox of hungry and malnourished farming families; the continent continues to be a global hotspot for food and nutrition insecurity and is home to some of the world's poorest populations; and food aid has virtually become a perennial feature, particularly in SSA (Gliessman and Tittonell, 2015). More critically, in contrast to other continents, agricultural productivity in Africa has continued to decline (van Ittersum et al., 2013). The agricultural production practices and value chains remain underdeveloped as a result engaging in agriculture in the region remains less attractive to the young generation (Ströh de Martínez et al., 2016).

The variety of resources, productive and non-productive, as well as livelihood specific assets like land and livestock including various phases of production to the consumption of food through distribution and processing in the food system, consists of a more complex adaptive system. Despite the complexity of biophysical and socio-economic components of the food system, attempts to understand and improve its efficiency in SSA remained sectoral, fragmented and simplistic, and hence have thus far been less successful. Population pressure has continued to increase, and the resources base are depleting. The challenge is compounded by climate variability and change, under development of infrastructure and markets that continue to affect people and agriculture in SSA.

The various components of the resource base (soils, crops, livestock, weather, etc.) and socio-economic elements (culture, farm management practices, knowledge systems, non-farm and off-farm income generating activities) and many other factors interact in complicated ways to influence agricultural productivity and sustainability of production systems. The development and adoption of sustainable farming systems require a better understanding of the ecology of farming systems, the socio-economic aspects of the communities managing the production systems, and capacity to identify and use options for sustainable intensification and to overcome barriers to adopt good practices. According to Tilman et al. (2002), fundamental shifts in policies, incentives, and institutions will be required in the search for, extensive adoption of sustainable agricultural practices; that search must be an on-going and adaptive process.

Most of the agricultural researches being conducted to benefit the poor in SSA are hampered by the historical lack of cross-disciplinary linkages and cross-sectoral approaches (Lenné and Thomas, 2006). Failure to address challenges in an integrated manner continues to limit adoption and use of most agricultural research results by smallholders. As a result, many continue to poorly understand and address interactions that contribute to poverty alleviation, food security, and sustainable resource use by smallholders in SSA (Mortimore, 1991; Kristjanson and Thornton, 2001).

Working at an integrated level in crop-livestock systems provide opportunities for the improvement of the two production components of sub-systems at the same time (FAO, 2010). It allows improvements in the workforce, the stability of production and reducing production related risks; greater chances of producers reaching their socio-cultural aspirations; and greater food security to meet the needs of consumers regarding the diversity and quality of products they may get at a given point in time. A high level of biodiversity (Mores et al., 2014) is maintained that further supports the sustainable agricultural systems, ensure food availability while also reducing environmental degradation and assisting agriculture to adapt to climate change.

By definition, therefore, a complex adaptive system is a system composed of many heterogeneous pieces whose interactions drive system behavior (National Research Council, 2015). Ignoring these characteristics can distort our picture of how these systems work, causing policies to be less effective or even counter-productive (Levin et al., 2013). This result in situations where research recommendations do promote either intensive cropping or livestock production in cases where farmers' objectives and resources would have supported further integration (Kassa et al., 2011). As a result, most recommendations fail to be adopted by smallholder farmers. On the other hand, Endashew (2017) description of food and nutritional security along with hunger alleviation on a global scale can only be within reach if technological innovations are accepted, promoted and implemented particularly at smallholder farm level.

The poor performance of the agricultural production that leads to food insecurity, persistent poverty, low-income levels and declining environment multi-functionality of production systems is not a mere effect of technical and financial scarcity. It is related to the lack of adequate information on area-specific resources and how the agricultural system evolves at local, regional and national levels. This is particularly true in a region where extension packages are designed and promoted assuming that smallholder farming systems are uniform and mixed farming systems need to specialize in crop or livestock production systems. That is, not only the extension systems, but the policy direction also fails to take into account the reality of the existing integrated crop-livestock production systems (Kassa et al., 2011) in many developing countries.

Most researchers and policymakers fail to realize the the available land use, biomass base, labor, draft power and manure that are utilized in a way to meet subsistence interaction levels between crop and livestock production systems in energy and nutrient links, which complement food and cash needs of the farm households.

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It is also true that all interaction effects are not always positive. Smallholders are facing food insecurity, high capital shortage, and high risks associated with agricultural production. Unless the innovation works under the real circumstances of the smallholder systems, its adoption will naturally be slow. Given the challenges, they continue to minimize risk and optimize total farm productivity than maximize a specific crop or livestock productivity. Thus, it is important to think through how their efforts can be assisted to increase productivity through increased efficiency of use of resources available (or can be made available) to them.

Smallholder farmers operating crop-livestock production systems in SSA often manage fragmented holdings and face annual and intra-seasonal variability of climate factors; they depend mainly on family labor with poor access to transport services and the market, limited availability of extension and credit services. As a result, smallholder producers hardly benefit from the growing national and global demand for agricultural products.

Designing development interventions and devising an agricultural policy that works for smallholder farmers in SSA calls for better understanding of the production objectives of smallholders and the functional and organizational structure of mixed crop-livestock farming systems. This review focuses on the description and importance of integrated biomass base crop-livestock production system building on cases and identifies entry points to enhance food security and reduce poverty amongst smallholder farmers in the SSA.

## INTEGRATED CROP-LIVESTOCK PRODUCTION IN THE FOOD SYSTEM

### Biomass base of integrated crop-livestock systems

In integrated systems, biomass base is defined as nutrient flows, linking crops, livestock and human components of agriculture, whereas the land is a spatial framework of the flow path. The spatial dimension is key to the concept of material cycles and energy flows, and management of integrated systems and flow paths connect a point of origin to an end by displaying a spatial distance (Poccard-Chapuis et al., 2014). The rural production system consists of a spatial structure and social scale in the concept of biomass base that integrates system components in complex ways and with interdependence. Spatial structure can matter by directly shaping the local context experienced by actors, but it also can shape impacts at a distance and affect changes in the environment over time (National Research Council, 2015). Development and adaptation of integrated systems analysis, therefore, must include different technical, social, demographic and environmental functional relations that are defined simultaneously on different hierarchical levels to gain a better framework of the complex problems of our society.

Agro-systems are complex systems of topographical sequences which usually contain a variety of distinct pathways. For instance, in Southern Mali, the landscape relief determines the soil type and its potential for production whether native or cultivated (Kante, 2001). The upland portions have more fragile soils with a coarse texture and low fertility than the lowland sections. Where in latter, soils were deeper with a higher percentage of clay and were fertile due to water flows in the watershed (Riou, 1990), and from a sociological view, village residents were sorted along the topography by inhabiting the uplands (Dufumier, 2004). Native vegetation areas are community property where the pastures and forests are used communally during the non-growing period, whereas cultivated land is managed privately during the crop production season (Poccard-Chapuis et al., 2007). A village leader defines rules for common use of the areas (Hardin, 1968). Farming practices based on the cut and burn system continued to be practiced up to the first half of the 20th century, with regeneration cycles of about 20 years as indicated in Mali situation. At that time the upland portions of the topography were preferentially cultivated due to finer vegetation that was easier to clear (Riou, 1995). The return of ashes from burned forests was compensated for such soils common low chemical fertility, which was also a technique to make the land to work easier (Poccard-Chapuis et al., 2007). As such, fields are spread across the topography, allocated by traditional authorities and family heritage management takes into account the spatial structure of the property. Thus, each property has a unique spatial distribution among the three types of fields (non-manured fields, manured fields, and bushland) and size of cattle herds (Lemaire et al., 2011).

With consolidation of permanent fields, the limited quantities of chemical fertilizers distributed by agribusiness became insufficient to correctly manage the soil; farmers were interested to utilize manure from cattle herds to improve fertility of cropland soil, such that cropland became an essential part of the fodder calendar, especially in the dry season, whereby cow dung from the grazing cattle was deposited directly on cropland (Poccard-Chapuis et al., 2007). Biomass recycling is the linchpin of maintaining and enhancing animal and plant productivity along with investment in capital and labour use.

### Optimizing crop and livestock component within biomass base

According to Kumaraswamy (2012), environmental sociology is increasingly becoming indispensable in the restoration of ecological functions. Hughes (1995) and Cooke and Kothari (2001) defined environmental sociology as complex symbolic and non-symbolic reciprocal interactions between society and environment that are influenced by the cultural and social behavior while interacting with the physical and biological elements. The rural landscapes have inherent physical and functional characteristics that determine to some extent necessary spatial structure (Poccard-Chapuis et al., 2014). The functional improvements in rural landscapes can occur over time with consideration of crop and livestock components in space (Poccard-Chapuis et al., 2011). Rangeland (non-food production) biomass with native vegetations and grasses in many rural regions are still larger than the food production biomass base. Substantial refinement has not been done yet on spatial arrangements. A case study shows that the productivity gains are potentially high through the recovery of degraded pastures and formation of eco-efficient from arrangements of various components of the landscapes (Poccard-Chapuis et al., 2014). Herrero et al. (2013) reported that grasslands are sometimes considered either underused or seen as an ecosystem warranting judicious management because of their importance for protecting key regulating ecosystems services (carbon, biodiversity, and water). Farmers will need to identify characteristically different parts of their farmland, such as hill sides, plains, wetlands, river banks, etc., in order to develop an efficient spatial arrangement of land use and appropriate management practices for optimizing production and use of biomass and water. In the grassland areas, the arrangement should be thought of as a process of progressive pasture reform, with occasional diversification into other uses, and with a greater appreciation of where animal manure is deposited (that is, on pasture for temporal rotation with cropland or in the corral for collecting and spreading manure on cropland).

## Integrated management and role of institutions

Two specific cases have been cited by Poccard-Chapuis et al. (2014) to compare the productive performance of the integrated systems of Mali and the Brazilian Cerrado while also highlighting similarities from an ecological but differences from a social point of view. Management by the agribusiness company in the Brazilian Cerrado certainly facilitated several factors that Mali farmers lacked: access to finance equipment technical support, quality inputs, training and complementarity among specialized components. Food production in Brazil foods mobilized public policies to support efforts, particularly public funding for infrastructure development. Attempts to enhance an integrated system of food production was facilitated through direct control of livestock and cultivated areas (e.g., prices paid to farmers) so that complementarity of feed production, meat production and other components were ensured. The company, known as Brazil Foods, could monitor and adjust crops and livestock in the territory, as well as biomass circulation in the integrated system. Even transportation is managed by the company with a fleet of trucks and a dense network of passable country roads. Brazil foods were responsible for balancing this system, economically and agronomically. However, this integrated structure was faced with the risk that farmers wanted to invest in other production systems, such as sugarcane as this had attractive prices in neighboring regions. It is possible that a decline in grain supply would lead Brazil Foods to forego the territory and move its activities to another region. This is one limiting factor in managing a large corporation: it can optimize integrated crop-livestock systems, but it can also change strategy and withdraw, compromising the development direction of the territory. Therefore, the social system may be influenced by an uncontrollable external agent, affecting the viability of integrated crop-livestock systems.

In the case of Mali where the large company and support services and policies do not exist, management was left to the farmers themselves and traditional authorities. Biomass production, transport, and transformations are limited due to limitations in investment in technology, low level of capital to process plants and to buy inputs such as quality seeds and fertilizers. Public policies are poorly aligned with the needs of poor producers limiting the impact on the agrarian system. Moreover, traditional management has been facing difficulties in promoting new innovations and in enforcing certain management practices such as controlling grazing on communal land. This comparison clearly shows the role of managers in innovation, public policy to mobilize resources and support efforts to promote integrated management. The social system in villages combined with the former slash and burn and forest succession system can be considered hindrances to optimizing integrated systems at a regional scale. The trend is that farmers, as seen in the Amazon case, end up developing integration individually without the collective mobilization of potentially shared resources and biomass.

Attempts are being made in Africa so that agricultural research and knowledge generation strategies involve multiple-stakeholders and promote sustainable and equitable agricultural development. The Forum for Agricultural Research in Africa (FARA) supports efforts towards integrated agricultural research for development (Adekunle et al., 2012).

## Farm level integrated crop-livestock production systems

The coexistence of crop-livestock production systems in many different forms at a global scale is evidenced (Seré et al., 1995; Dixon et al., 2001). As a group of farms, they are assumed to be operating in a similar environment that provides a useful scheme for the description and analysis of crop and livestock development opportunities and constraints (Otte and Chilonda, 2002). Investment in agriculture to have a sustainable impact on food security and poverty and decisions have to be made with respect to smallholder farmers and their biophysical environment and socio-economic and cultural setting (Notenbaert et al., 2009); future scenarios modeling could be amenable ideally for these systems.

The impacts of agricultural production on the natural environment strongly depend on specific local conditions. Changes in water or nutrient cycles, for example, are related to soil conditions, terrain type and local climate condition (Lotze-Campen et al., 2005). In crop-livestock systems, the feed supply is defined to a large extent by the biomass produced on grazing lands and by crops that could be available for use as livestock feed (Fernández-Rivera et al., 2004). Estimations of feed surplus and deficit areas linked to potential stocking capacity can give an indication of current and probable future pressure on the natural resource base (Notenbaert et al., 2009). Other assessments include manure calculations, nutrient cycle, and land degradation. The value of animal traction for purposes of cultivation can legitimately be included as one of the potential assessment but information is rarely available even in countries where animal traction is predominantly used in crop production: cultivation, weeding threshing, transport, etc. It was estimated that in Ethiopia, the annual production of crop residues has increased from 6.3 million tons in 1980 to about 31 million tons due to the expansion of cultivated land and increased crop productivity (CSA, 2008). However, the use of crop residue varies from place to place in the country. A study by Amejo et al. (2017) reported that in smallholder crop-livestock systems, the feed source from grazing/browsing and from crop by products accounted for 92 and 8%, the total annual supply of livestock feed. The same study concluded that feed from rangelands biomass accounts for about 82% of the feed for livestock in the lowland areas of that study.

Earlier studies in Ethiopia indicated that about 80% of farmers use animal traction to plough their farm fields. In the Ethiopian highlands, the area under cultivation is positively associated with cattle ownership (Gryseels, 1988; Mergia et al., 2005; Bogale et al., 2009). Ploughing with cattle also increases crop output per hectare. In Oromia regional state of Ethiopia, farmers who used oxen or a combination of oxen and hand cultivation obtained higher yields of both teff and maize as compared to farmers using hand cultivation alone (Mergia et al., 2005). Assessment of livestock productivity in the mixed farming systems in Southern Ethiopia shows that cattle manure (dry matter produced in kg/year) and draught animal power accounted for 29% of the gross household income from the livestock sector (Amejo et al., 2018).

The Livestock Policy Initiative of the Intergovernmental Authority on Development (IGAD) reported that the mean weight of cow dung used for fuel by households in Ethiopia was equivalent to 293 kg per year per cattle (Behnke, 2010). The conventional methods used for agricultural GDP calculations fail to capture a wide range of economic benefits provided by livestock to the Ethiopian national economy. The IGAD policy brief recommendation asserted that in the interest of supporting more informed policies for livestock development, the Ministry of Finance and Economy Development and the Ministry of Agriculture should collaborate to supplement the standard national accounts with periodic estimations of the value of livestock goods and services that are underestimated in national accounts (Behnke and Metaferia, 2013).

Another comparative system analysis in three countries showed the net income issues from agriculture activities: the US $40 in Vihiga (Kenya), $284 in Upper West (Ghana) and $4,368 in Kandy (Sri Lanka). It demonstrated that the low incomes and the high reliance on off-farm income (92%) in Vihiga could be explained by small farm size and that the high proportion income obtained from sale of milk, on the other livestock could be a vehicle for intensifying systems without the associated effects of land-based intensification (Herrero et al., 2007).

## Role of production system characterization for integrated management

Integrated crop-livestock systems are organized to maximise synergies and minimize trade-offs between crops and livestock sub-systems through the production of crops and livestock on the same area, concurrently or sequentially in rotation or succession (Moraes et al., 2014). The result of an integrated system is that the whole is greater than the sum of its parts and resulting in having emergent properties (Anghinoni et al., 2013). These integrated crop-livestock systems are produce with minimal supply of inputs and technologies (Moraes et al., 2014).

## The role of research and development in integrated crop-livestock systems

Because of various constraints that smallholder farmers managing integrated crop-livestock production systems face, they have not been benefiting from research and development efforts to the extent expected. Infrastructural limitations and poor market access made farmers benefit little from growing demands for food in SSA and in the world at large. Thus research directions and development interventions need to focus on improving the policy and institutional aspects that enable farmers to increase total farm productivity and household income through improved links to technologies and services and better links to markets. More research and policy instruments are needed to improve resource use efficiency of integrated farming systems.

Efforts to improve crop-livestock systems therefore necessitate a detailed analysis of farmers' circumstances and practices of the components of production systems and their operation from various regions. White (1998) reported that opportunities for and constraints to improving the productivity, sustainability and viability of integrated farming systems are often specific to particular agro-ecological zones and socio-economic settings. Understanding the subsystem is an essential part of the bio-economic foundations of rural livelihood systems (Thornton and Herrero, 2001), which requires accounting for its component stocks, resource flows and interactions (Ashley and Carney, 1999).

## FOOD SECURITY AND POVERTY IN SMALLHOLDER PRODUCTION

The concept of food security is multidimensional in nature and includes food access, availability, use, stability and even entitlement to food. The analysis of food insecurity as a social and political construct has been growing in importance (Devereux, 2000). Poverty and food insecurity continue to be highly concentrated in SSA.

Reducing hunger and poverty calls for improvements in economic conditions of households and infrastructure, the organization of food production, the provision of social services, political and institutional stability, among others (FAO, 2013). In terms of natural resources, most of SSA countries have relatively abundant agricultural land. For example, in 2008, SSA allocated 29 million ha of agricultural land (about two-thirds of global demand), for foreign investment (Deininger and Byerlee, 2011). Gomiero (2016) emphasized the greatest potential for croplands in tropical Africa given current climatic conditions (560 million ha) followed by North and South America (470 million ha). Yet currently cultivated land in SSA is under smallholders with low productivity levels and managing less than 1 ha of landholdings (Deininger and Byerlee, 2011).

In Ethiopia, total land area cultivated for grain in 2016 was 14,934,373 ha and a total of 2,998,828 tonnes of grain was produced (CSA, 2016). Smallholder farmers accounted for 95.5% of the area cultivated, whereas commercial farmers accounted for 4.2% of the area cultivated and 0.3% of small-scale irrigation user. The same is true for livestock production where 98.59% of cattle population are local breeds (CSA, 2016). Livestock products supply chain is dominated by smallholders and pastoralists except very few per-urban farmers engaged in dairy and poultry.

The existing yield gap in productivity, the growing demand for food products and shortage and in some cases, absence of large-scale competitive commercial farmers in the agriculture sector provide opportunity for market oriented agricultural development that would raise smallholder productivity in many SSA countries (Deininger and Byerlee, 2011). Given the widespread rural poverty and small-scale farming in Africa, the conventional wisdom supports a strong role for agriculture in African development (Diao et al., 2010). However, emphasis to developing the agricultural sector and enhancing its contribution in rural development in SSA remain limited due to policy distortions against agriculture and narrow focus toward higher value export crops.

In low-income countries with high dependence on agriculture, strategies that promote agricultural productivity and link producers to markets are most appropriate for making progress in poverty reduction and, by implication, improving food security (Mellor, 1995; de Janvry and Sadoulet, 2001). The links between increased production and improved food consumption of poor and food-insecure persons are mediated through complex institutional and socio-economic relations, thus one should not just think of production increases alone to positively impact food security and poverty. As undernourishment handicaps, the efforts to improve food production, feedback effects between food production and consumption should be considered. A recent sustainable development agenda recognizes the need for eradicating poverty in all its forms and dimensions. This is the greatest global challenge and an indispensable requirement for sustainable development (Resolution, 2015). Thus, reduction and ultimate eradication of poverty and hunger are the most urgent tasks facing national governments in SSA. This necessitates significant public interventions to develop the agricultural sector, supporting rapid income growth that translates to increased capacity to produce or purchase food (FAO, 2013). Agricultural development, coupled with the expansion of rural non-farm activities are the most effective means of promoting income growth.

The term undernourishment is used to describe the status of persons whose food intake does not provide enough calories to meet their physiological requirements on a continuing basis (FAO, 1999a). As recommended by FAO/WHO, the body mass index (BMI) measure (the ratio of body weight in kg to the square of height in meters) is commonly used in adults group, and the considered range for healthy adults is between 18.5 and 25. The BMI can clearly vary over an adult's lifetime, but physical stature is determined by the time an individual reaches adulthood. It is critical to note that poor anthropometric status is the outcome not only of insufficient food intake but also of sickness spells.

The economic costs of malnutrition and undernutrition, often translated to poor anthropometric status of individuals. First, this limits physical strength of an individual and his/her ability to do sustained work often required among rural communities that are dependent on agriculture which requires much manual labour. This in turn limits capacity to generate more income. Poor nutritional status leaves people more susceptible to illness. Poor nutritional status is associated with a risk of intergenerational transmission. For instance, women who suffer from poor nutrition are more likely to give birth to underweight babies. These babies thus start out with a nutritional handicap. Poor nutrition is associated with poor school performance in school-age children as prolonged and severe malnutrition are known to impair the cognitive ability of the child. People who live on the edge of deprivation do follow a policy of safety rather than to invest in agriculture. Finally, the macroeconomic performance of the whole economy will continue to suffer from the cumulative impact of all these effects.

Several studies reported that increased BMI had a significant impact on output and wages. For example, Croppenstedt and Muller (2000) found that in rural Ethiopia, an increase of 1% in BMI increased farm output by about 2.3% and wages by 2.7%. Thomas and Strauss (1997) found that a 1% increase in BMI in their sample from urban Brazil was associated with a 2.2% increase in wages. Strauss and Thomas (1998) presented a succinct and illuminating review of the impact of adult stature and BMI on productivity through an analysis of two data sets from the United States and Brazil. They found that adult stature is positively correlated with wages in both countries, but the effect is strong in Brazil and weak in the United States. The implications of the findings are profound. The loss of income to those suffering from undernutrition can be large. Thus, it appears that in Brazil, people with BMIs of 26 earn wages that are considerably higher than wages earned by those with a BMI of 22. Furthermore, people with BMIs of 26 are far more likely to find work than people with BMIs of 22.

A significant impact of increased calorie consumption on farm output and wages has also been reported. For example, a study by Thomas and Strauss (1997) found that an increase of 1% in calorie intakes increased wages by about 1.6% at calorie intake levels of around 1700 calories per day, but that this effect ceased to operate after calorie consumption levels reached around 1950 calories per day. Increased attention is being given to the role of micronutrient deficiencies in reducing labour productivity. Iron deficiency that causes anaemia was associated with a 17% loss of productivity in heavy manual labour and 5% in light blue-collar work.

The importance of subclinical vitamin A deficiency in child mortality has been recognized through meta-analysis of clinical studies (Horton, 1999). The relative risk of mortality for a child with subclinical vitamin A deficiency is 1.75 times than that for a child who does not suffer from this deficiency. Horton (1999) has provided a measure of the overall economic costs of malnutrition as a percentage of GDP for selected Asian countries. An FAO report (Arcand, 2001) has indicated a strong relationship between economic growth and nutritional factors, as measured by either the prevalence of food inadequacy or gap in the dietary energy supply per capita. The impact of nutrition on economic growth appears to be strong to operate directly, through the impact of nutrition on labour productivity and indirectly through improvements in life expectancy.

According to Fogel (1994), improvements in nutrition and health explain half the economic growth in the United Kingdom and France in the eighteenth and nineteenth centuries. An accounting approach with concepts from demography, nutrition and health sciences by the same author has stressed the physiological contribution to economic growth over the long term. A change in diet, clothing and shelter together with a reduction in the incidence of infectious diseases, increased the efficiency with which food energy was converted into work output and translated into higher economic growth.

Private income growth alone does not guarantee improvement in nutritional status. Nutritional status is the resultant of food intakes and health inputs. Thus, the solution to undernutrition is increased intakes of calories as well as improvement in micronutrients, better health and sanitation, safe drinking water, better functioning markets, etc. (FAO, 2013).

## Rural poverty

Rural poverty remains entrenched among smallholders managing integrated crop-livestock production systems. More need to be done to enhance our understanding of what works in terms of reducing poverty reduction and enhancing food security. In particular, the focus should partly shift from the pursuit of win-win policies towards policy options that involve managing trade-offs and maximizing synergies between crop and livestock production systems on one hand and between agriculture and non-agricultural income generating activities on the other hand with which policymakers are more often confronted (FAO, 2013).

Smallholder farmers in SSA are engaged in largely subsistence farming and are dependent on often disconnected local food markets (Ströh de Martínez et al., 2016). The defining characteristic of most goods and services of smallholders is that they are effectively less tradable due to their marketable quality and/or volume. Most produces of smallholders are found in less accessible locations. The growth of smallholder produce is conditioned by the growth of demand in the local rural market. Devising strategy for agricultural growth that promotes productivity and income of smallholder and hence allows for greater participation of the poor is central to reducing poverty and promoting rural development in SSA (Diao et al., 2010).

## PATHWAYS TO DEVELOP INTEGRATED CROP-LIVESTOCK SYSTEMS IN SUB-SAHARAN AFRICA

Co-existence of crop and livestock in traditionally integrated crop-livestock production systems has evolved from age-old practices that attempt to use available inputs and increase total farm productivity. Smallholder farmers are experienced in adapting their systems and methods of production to different circumstances, albeit slowly and with only a limited success as they have not been systematically supported by governments in terms of adoptable innovations, supportive policy instruments and market links. As circumstance change to alter one or more of the constraining factors, farmers may adopt their systems of operations.

A study in Tanzania showed that though limitations in farm size, capital and technological development and market access remain challenging, there exist means to increase agricultural production via improving technical efficiency (Hepelwa, 2010) and to use appropriate extension and other support services to better understand obstacles for scaling up (Nijbroek and Andelman, 2016).

Swanepoel et al. (2010) suggested that the institutional, market and policy-related constraints that undermine productivity and income levels of smallholder framers in SSA need to be identified and addressed in a coordinated manner. Transportation, infrastructure, markets and institutions are critical for establishing efficient markets but are often severely lacking in livestock-raising areas (PicaCiamarra, 2005). According to Moraes et al. (2014), integrated crop-livestock systems can support efforts for the sustainable intensification of agriculture. Promoting increased production of foods, fibres and energy, associated with the promotion of ecosystem services is assisted by supporting further intensification through integration of crop-livestock systems. Crop-livestock systems in SSA vary (Ruthenberg, 1971) arising from the combination of parts that have different operational features. Though a number of constraining factors limits a range and balance of resource and enterprise combinations that are found in any specific farming system, these production systems continue to adapt to and respond to demands of markets (Swanepoel et al., 2010). Focus on market-orientated smallholder production systems helps intensification that help to significantly close yield gaps in crop and livestock production, and bring about efficiency gains by reducing opportunity costs for, among others, land (Naylor et al., 2005).

It is necessary to properly consider agro-ecological, technical, social, demographic and environmental factors as attempt is made to develop integrated crop-livestock production systems on which most smallholder farmers in SSA depend for their livelihoods. Agro-ecology offers technical and organizational innovations to promote a restorative, adaptable, inclusive and resource use-efficient agricultural model at global scale, however, there are several challenges ahead. It is assumed that scaling up agro-ecology from successful isolated examples of pioneer farmers to broad-scale dissemination will be next major challenge. Investing in institutional and policy innovation will be at least as important as investing in generating new scientific knowledge on agro-ecology. The social-change aspect of agro-ecology was strongly voiced by the organizations supporting and promoting the rights and needs of food insecure and malnourished communities (Gliessman and Tittonell, 2015).

For example, policies that set the rules of the game by internalizing the environmental externalities in production costs, through preferential allocation of subsidies to low environmental impact farming; through the protection of family farmers' rights to access agro-biodiversity, which is increasingly being restricted by patents and unethical claims on property rights; and through the promotion of short commercialization circuits and local food systems, including processing, that can guarantee quality and safe food for the poorest. Policies that set the rules of the game to make agro-ecological farming as competitive and economically viable as industrial farming will be able to better inform the development of public policies to support the rural poor transition rather than policies that compel farmers to embrace agro-ecology.

Small farms could play a more significant role by complementing and reinforcing diets through the production of a large diversity of nutritious crops, rather than focusing on producing only calorie-rich crops in a context of rapidly increasing population and dwindling farm sizes. The case of smallholder rural families may constitute an exception in many situations. The average diet of people in rural areas that are well connected to markets and urban hubs, or that have access to mass communication media, is increasingly determined by demand. Yet, in regions that are less connected to markets or to mass media, or where poverty prevents people from affording external foods, the relationship between landscape and nutritional diversity is a much stronger one. The functional biodiversity that is necessary to sustain agro-ecological processes and functions also results in a greater diversity of crops and animal products that can improve the diet of farming families, aforementioned as in the case of Brazil.

It was evidenced that currently, global food production is short of vegetables by 11%, fruits by 34%, fresh milk by 50% and nuts and seeds by 58%. These nutritional gaps indicate that there is a need to diversify production through, e.g. intensive vegetable rotations and associations, crop-livestock integration, or fruit tree agroforestry, all practices that are common in agro-ecology.

Efforts should be directed towards the design of nutrition-sensitive landscapes by means of diversification. The good intention of increasing the yield of a few world commodities to reduce poverty and hunger has already shown its limitations. Particularly in smallholder family agriculture, when land sizes are as small as one acre or less, increasing the yield of staple crops will not result in families rising out of poverty. Given their small size, the

**Table 1.** The four dimensions of any food system and their effects.

| Dimensions | Domains | | |
|---|---|---|---|
| | **Health** | **Environment** | **Social and Economic** |
| Quantity | All households to an extent meet their food requirements in terms of energy (and protein), without malnutrition | Increased system productivity of biomass based values | Rising disposable income of poor household |
| Quality | Availability of food with adequate micro-nutrients | Rehabilitate and maintain biodiversity of natural environment and traditional agriculture scenes | Variety of affordable food for households with different income levels |
| Distribution | Access to a variety of food for all groups in population at all seasons | All weather condition accessible infrastructure and communication across agro-ecology, topography and river boundary | Affordable cost to move smallholders on-, off-farm supply; appropriate prices to the supply and their demand at all seasons |
| Resilience | Quality and healthy food in recovery of wasting, stunting and underweight | Sustainable interconnection and communication of community across agro-ecology, topography and river boundary, as well as secure access to communal resources | Community retains viability after loss either endogenic or exogenous economic source |

Source: National Research Council (2015).

total income they may receive from selling their harvest, even if they produce at potential yield levels, will still be meagre. The result is that a large number of farmers in SSA regions are currently part-time farmers who are unable to pay enough attention to their farms and their landscapes. This trend will be exacerbated for future generations of family farmers unless something is done about it. It is time for agr-oecology.

Gliessman (2015) said that agro-ecology must integrate science, technology and practice, and movements for social change help to re-connect the people who grow the food and the people who eat the food in a relationship that benefits both. Food system interventions are more likely to succeed if they are informed by an understanding of the intrinsic dynamics associated with production systems, public health, environmental, and social and economic outcomes with an appreciation that their interactions are non-linear and not always readily predicted (National Research Council, 2015). Along these important dimension, Table 1 shows a summarized presentation of a conceptual framework adapted from the National Research Council (2015) to measure the effects of these important dimensions on food systems. Within an agro-ecological food system perspective with focus on localized units and from an agro-ecological standpoint, clearly the definition of system boundaries can be made explicit.

For example, integrated system analysis to ensure the roles, extents and potential demand of the resource base can confer certainty of the long-term impact of increased efficiency for food production and sufficiently high economic return in line with land capability. This approach can help planners and smallholders set future directions, and make decisions as to how to reallocate the resources without affecting existing economic and ecological basis of food production and non-food production biomass. It gives efforts to improve the efficiency of food availability, enhances resources use efficiency and attains food security without substantially degrading the natural resource base.

Government policy is an important factor that governs the development and evolution of farming systems. Government efforts also include efforts to establish and strengthen research institution and development actors at large to support rural economic development. The support provided by non-governmental organizations to help the community improve its productivity and income cannot be underestimated. The role of the private sector however remains limited. The central role of the government in coordinating development efforts to develop smallholder integrated crop-livestock systems in SSA remains central. Technical and institutional options to enhance the role of this production system to reduce poverty and food and nutritional insecurity which promote interaction of the two sub-systems, crop and livestock should be adopted, rather than attempting to increase productivity of only crops or only livestock in SSA.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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