Chapter

# Crops Diversification and the Role of Orphan Legumes to Improve the Sub-Saharan Africa Farming Systems

*Patricia Vidigal, Maria Manuel Romeiras and Filipa Monteiro*

## Abstract

Agriculture is the main economic revenue in sub-Saharan African countries, playing a key role on smallholder livelihoods as household incomes and as food. Food insecurity is known to increase with the inevitable climate changes, which already affect the major farming systems, sub-Saharan Africa (SSA) being particularly susceptible, mostly due to the high dependence of rainfall for crop cycles. As such, to promote food security in a long run, new farming systems have to become more sustainable and productive at the same time. In this chapter, a global overview of major farming systems in sub-Saharan Africa is provided, and current and future production scenarios are discussed. Moreover, some of the major pillars under the sustainable land use intensification are highlighted, and the potential of the undervalued African legumes toward a sustainable crop production is debated. Finally, an outline of key opportunities to diversify cropping systems is explored along with the benefits associated to integration of local and "orphan legumes" that are considered. It is argued that the use of these "orphan legumes" and the implementation of appropriated management approaches will promote a sustainable production of more food from the same land area, relying on mutually beneficial ecological relationships and reducing environmental impacts.

**Keywords:** orphan legumes, sustainable production, farming systems, sub-Saharan Africa

## 1. Introduction

In the past 50 years, global crop production has expanded, driven largely by higher yields per unit of land and crop intensification, resulting from multiple cropping and/or shortening of fallow periods [1]. The expansion of arable land area allocated to crops has played a less important part in production increases. However, these trends are not uniform across regions. For instance, most of the growth in wheat and rice production in developing countries in the land-scarce regions of Asia and Northern Africa has resulted in yield gains, while expansion of harvested land is a result of rapid production growth of maize in Latin America and the Caribbean and in sub-Saharan Africa (SSA) [2]. Yield growth contributed only one-third of the increase in crop production in the latter region. The arable land area in developed countries peaked in the mid-1980s and has fallen at an accelerating rate ever since. SSA is scientifically known as a rich niche of plant diversity which, in conjunction with local and traditional knowledge, makes the perfect combination to promote a sustainable solution for professional and smallholder farmers while respecting their livelihood needs, traditions, and market demand.

Economic foundations of most SSA are dominated by agriculture, which is recognized to contribute between 15 and 40% of the gross domestic product (GDP). Besides, agriculture sector provides livelihoods for over 70% of SSA's population through family farming [3, 4]. The economically active population in agriculture doubled from 100 million people in 1980 to 212 million in 2013. Considering that 75% of the SSA population is involved directly or indirectly in farming and related employment, the strategic role of family farms, mainly by women, has been recognized by key actors [5]. Over the last 40 years, the SSA population has been increasing from 279 to 826 million people, both in rural and urban populations. It is expected that due to the climate changes, there will be an increase in rural-urban migration as a consequence of agriculture abandonment and toward the search for better opportunities for both livelihoods and work, which will also cause an expansion and reclassification of urban boundaries [6]. As a result, by 2050 about 50% of SSA's population will be living in towns and cities [7]. In fact, a migration from rural-to-urban areas has been increasing at a fast pace (**Figure 1**).

To answer the increasing growth in consumers, production growths have stemmed mostly from area expansion at the expense of biodiversity, cultural value, and the rise in greenhouse gas emission (GGE). To respond to both market needs and the feeding of continuously growing population, crop production has been marked by extensive growth of staple crops, namely, in SSA. Over the last 20 years, crop staple production has risen at the cost of more land for agriculture. By 2014, most of African arable land was occupied by staple crops with more than 80 million hectares (ha), and the major contributors are maize, sorghum, and millet,

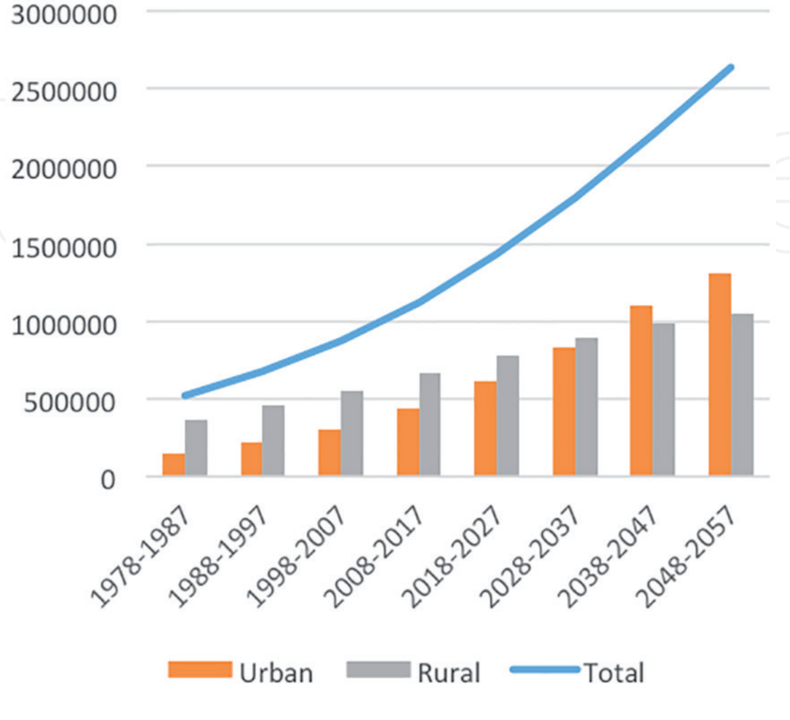


**Figure 1.**
*Annual growth of population in rural and urban regions in sub-Saharan Africa within the period of 1950s and to future projections until the 2050s [7].*

accounting for 80% of total food production. From the 1960s to the 1970s, there was an increase of 1 million ha dedicated to maize that increases by the 1980s with more 3 million ha, and from them on, there has been an increase of 4 million ha for every decade [7]. When restricting to the top six agriculture commodities in SSA region on FAOSTAT data [7] (**Figure 2**), major crops were analyzed in terms of production (A), area harvested (B), and yield (C), and key staple crops were highlighted, namely, rice, cassava, sorghum, and grain legumes/pulses, along with maize.

Maize is the crop that occupies the largest portion of agriculture land use, with an increasing area harvested devoted to its production that does not translate to an increment on crop production and thus yield. However, its production has been in an increasingly trend due to maize being Africa's most important food crop, and it is held up as a model food crop to meet Africa's growing urban demand for convenient food products [8–10]. Maize production, however, is risky because of unpredictable rainfall. On the other hand, cassava is known as Africa's second most important food staple in terms of per capita calories consumed, as a major source of calories. Accordingly, cassava production is among the higher number in SSA, occupying less agriculture land but with increasing steady production, translated in high yields. For instance, investment from the Bill & Melinda Gates Foundation in projects such as accelerated varietal improvement and seed delivery of legumes and cereals in Africa (AVISA) has contributed to more efficient cassava varieties. Yet, cassava has several other advantages over rice, maize, and other grains as a food staple in areas where there is a degraded resource base, uncertain rainfall, and weak market infrastructure. It is drought tolerant; this attribute makes it the most suitable food crop during periods of drought and famine. Cassava has historically played an important famine prevention role in Eastern and Southern Africa where maize is the preferred food staple and drought is a recurrent problem. While rice is produced in vast areas of the world, the physical requirements for growing it are limited to certain zones. Economically viable cultivation typically requires high average temperatures during the growing season, abundant supplies of water applied in a timely manner, smooth land surfaces to facilitate uniform flooding and drainage, and a subsoil stratum that inhibits the percolation of water. The bulk of world rice production is destined for food use and is the primary staple for more than half of the world's population. In recent years, rice has also become an important staple throughout Africa as part of the changing dietary habits. However, rice production requires high workforce and has limitations due to low mechanization of major SSA countries, which makes rice a crop usually bought at higher prices, without increasing its production.

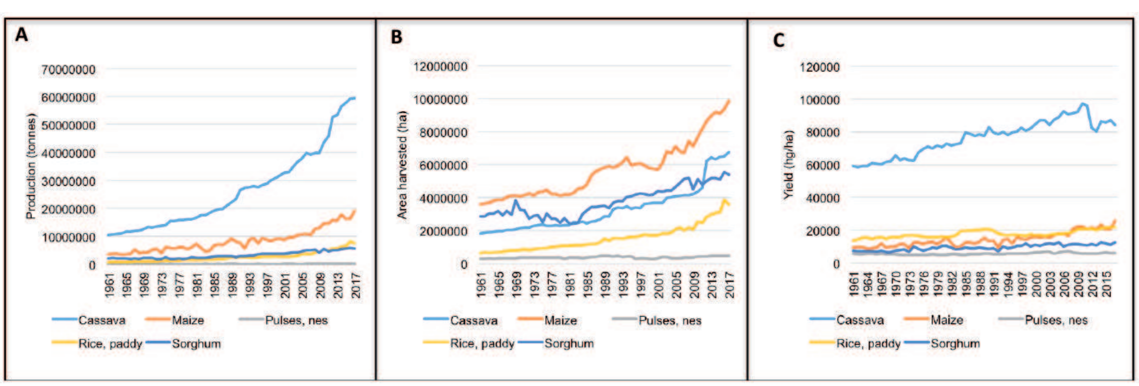


**Figure 2.**
*Top six agriculture commodities in the sub-Saharan Africa region, in terms of production (A), area harvested (B), and yield (C), from the period 1961 to 2011 [7].*

Considering this overall trend of major staple crop production in SSA region, it is undeniable that agricultural growth will contribute to poverty reduction, within a sustainable crop production scenario. A great diversity of farming systems across SSA shapes the current agriculture production in the region. Thus, in this chapter, we first provide an overview analysis of the major farming systems in SSA along with agroecological zoning, which delivers clear evidences on the sustainability of current agriculture production. After, we pinpoint how to ally sustainable intensification to integrated land use in SSA farming systems, by recurring to intercropping systems focusing on pulse crops (grain legumes, which are grown primarily for their edible seeds) and more particularly on legumes that have been named orphan legumes. Orphan, or underutilized, legumes are domesticated legumes with useful properties but with less importance than major world crops due to use and supply constraints. However, they play a significant role in many developing countries, providing food security and nutrition to consumers, as well as income to resource-poor farmers. Being legumes, these plants have the advantage of fixing atmospheric nitrogen for their own needs and for soil enrichment, thereby reducing the cost of fertilizer inputs in crop farming [11].

## 2. Farming systems in sub-Saharan Africa: an overview toward sustainable intensification

The diversity of agroecological zones (AEZs) across SSA (**Figure 3A**) results in the wide range of farming systems. According to the availability of natural resources (land, water, grazing areas, and forest) and climate, especially length of growing period and altitude, as well as the pattern of farm activities and household livelihood, African farming systems can be classified in 15 farming classes (**Figure 3B**). AEZs are climate-based and are a useful basis for determining the general suitability and production potential of crops and livestock in any given area. Thus, by matching AEZs with SSA farming systems, one can disclose potential or constraints toward SSA farming system (**Figure 3B**), by using a correlation analysis on agroecological zones and farming systems area based on HarvestChoice data (https://harvestchoice.org/).

From the 15 farming systems in SSA, there are 5 that occupy a higher percentage of the SSA region: (1) maize mixed, (2) arid pastoral oases, (3) pastoral, (4)

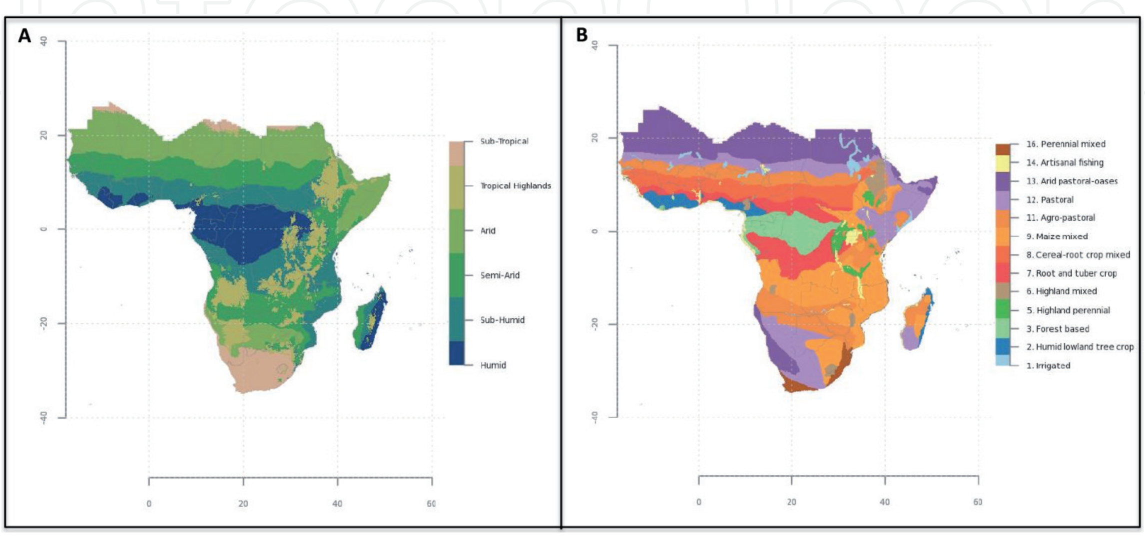


**Figure 3.**
*Farming systems and agroecological zones in sub-Saharan Africa. (A) Agroecological zones 5-class [12]; (B) farming system classes [13].*

*DOI: http://dx.doi.org/10.5772/intechopen.88076*

| Farming systems | SSA (%) | SSA regions (%) | | | | Agroecological zones (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | EA | MA | SA | WA | Arid | Humid | Semiarid | Subhumid | Subtropical | Tropical highlands |
| Irrigated | 0.9 | 0.8 | 0.1 | 0.1 | 2.1 | 1.7 | 0.0 | 2.2 | 0.0 | 0.0 | 0.1 |
| Agropastoral | **15.3** | 20.2 | 10.7 | 16.5 | 14.4 | 6.0 | 1.7 | 47.9 | 3.8 | 0.3 | 18.7 |
| Pastoral | **15.5** | 21.0 | 3.3 | 40.4 | 10.9 | 27.5 | 1.9 | 19.4 | 1.7 | 36.1 | 12.8 |
| Arid pastoral oases | **17.1** | 3.1 | 10.8 | 13.7 | 40.1 | 62.5 | 0.0 | 0.0 | 0.0 | 32.8 | 2.4 |
| Artisanal fishing | 2.0 | 3.9 | 1.3 | 0.0 | 1.9 | 0.3 | 3.6 | 1.3 | 5.2 | 0.0 | 0.6 |
| Perennial mixed | 1.6 | 0.3 | 0.0 | 11.3 | 0.0 | 0.0 | 0.0 | 1.3 | 0.5 | 15.2 | 0.5 |
| Humid lowland tree crop | 2.9 | 1.3 | 1.9 | 0.0 | 6.8 | 0.0 | 14.2 | 0.0 | 4.1 | 0.0 | 0.0 |
| Forest based | 6.0 | 0.0 | 20.1 | 0.0 | 0.2 | 0.0 | 41.6 | 0.0 | 0.9 | 0.0 | 0.1 |
| Highland perennial | 1.9 | 5.6 | 0.8 | 0.0 | 0.0 | 0.0 | 1.1 | 0.1 | 1.2 | 0.0 | 11.5 |
| Highland mixed | 2.2 | 5.3 | 1.1 | 2.1 | 0.2 | 0.0 | 0.7 | 0.4 | 1.1 | 3.1 | 12.2 |
| Root and tuber crop | 9.8 | 0.8 | 27.0 | 0.0 | 5.4 | 0.0 | 30.0 | 0.0 | 25.0 | 0.0 | 2.4 |
| Cereal root crop mixed | 7.2 | 0.6 | 6.7 | 0.0 | 18.0 | 0.0 | 0.0 | 8.8 | 24.6 | 0.0 | 0.6 |
| Maize mixed | **17.7** | 36.9 | 16.4 | 15.8 | 0.0 | 2.0 | 5.3 | 18.6 | 31.9 | 12.5 | 38.0 |

**Table 1.**
*Percentage of prevalence of each farming system in all SSA, in each SSA regions, and in different agroecological zones [12, 13].*

agropastoral, and (5) root and tuber crop (**Table 1**). The most prominent farming system in SSA is maize mixed, occupying 18% of SSA, especially in East Africa (37%) with the prevalence of the AEZ subhumid, semiarid, and tropical highlands (**Table 1**). East Africa tropical highlands and subhumid highlands have a bimodal rainfall pattern offering farmers two cropping seasons, but in drier areas such as semiarid AEZ, farmers usually harvest only once a year. This farming systems is one of the most important food production system in East Africa, with only 6% of the irrigated area in SSA [14], thus depending mostly on rainfall (**Figure 4**).

Considering a projection of increased number of drying days over East Africa [17] and a 0.96% annually increasing temperature (**Figure 5A**), the sustainability of this farming system is of great concern, and there is an urgent need of capacity building in crop management technologies, such as nitrogen efficiency in rainfed systems. The main staple crop in the maize mixed farming system is maize, with the main income being migrant allowances, cattle, small ruminants, tobacco, coffee, and cotton, plus the sale of food crops such as maize and pulses [14]. In the past, most of the production has been boosted by a subsidized combination of high doses of inorganic fertilizers and hybrid maize varieties. Once subsidies were removed, the use of high-cost inputs on maize became unprofitable, and the majority of smallholders reverted to traditional varieties with low to no market value, resulting in low household income. Although maize is the main crop, the intercropping system exists with pulses, oil seeds, cotton, sorghum, and millet. Intercropping with pulses, such as common bean, cowpeas, and soybeans, is common where landholdings are small and there is less pressure on the land. Most of the area occupied today by the maize mixed system was heavily afforested as farmers have pushed arable land into the forests, decreasing biodiversity to increase area devoted to commercial species. Pressure on the land to respond market needs led to problems related to declining soil fertility in combination with long dry seasons resulting in lower crop yields, food insecurity, hunger, and poverty [18]. Nevertheless, maize mixed is one of the farming systems that has a good long-term agricultural growth prospects with high potential for poverty reduction [14], which is reflected in East African lowest annual percentage of prevalence of severe food insecurity (**Figure 5A**).

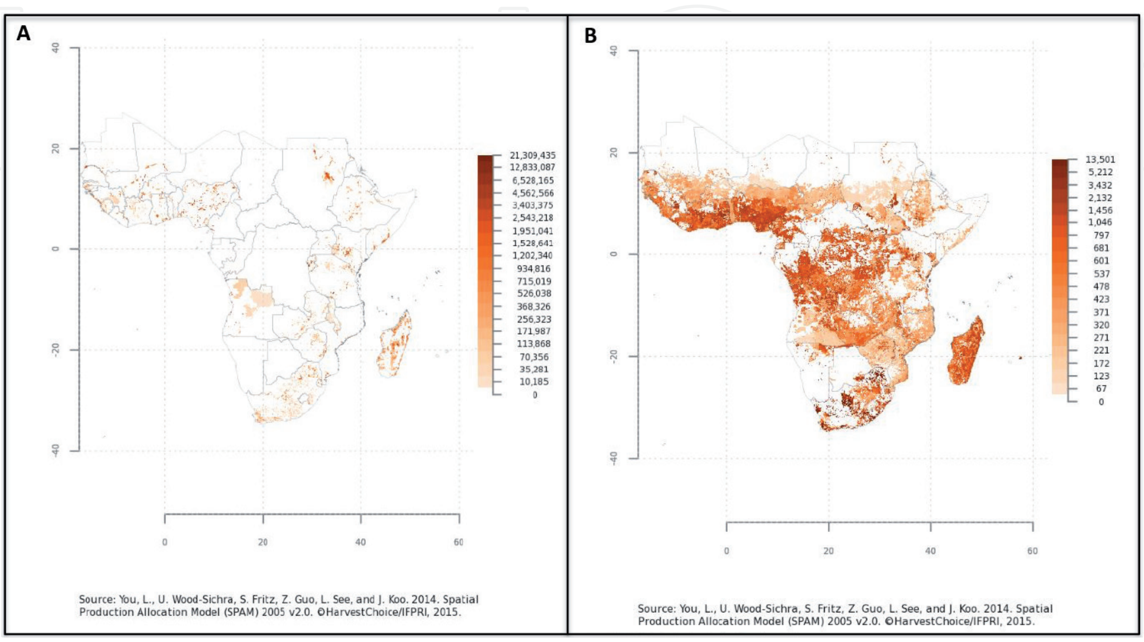


**Figure 4.**
*Food crops irrigated (A) and rainfed (B) value production (Int$, 2005) [15, 16].*

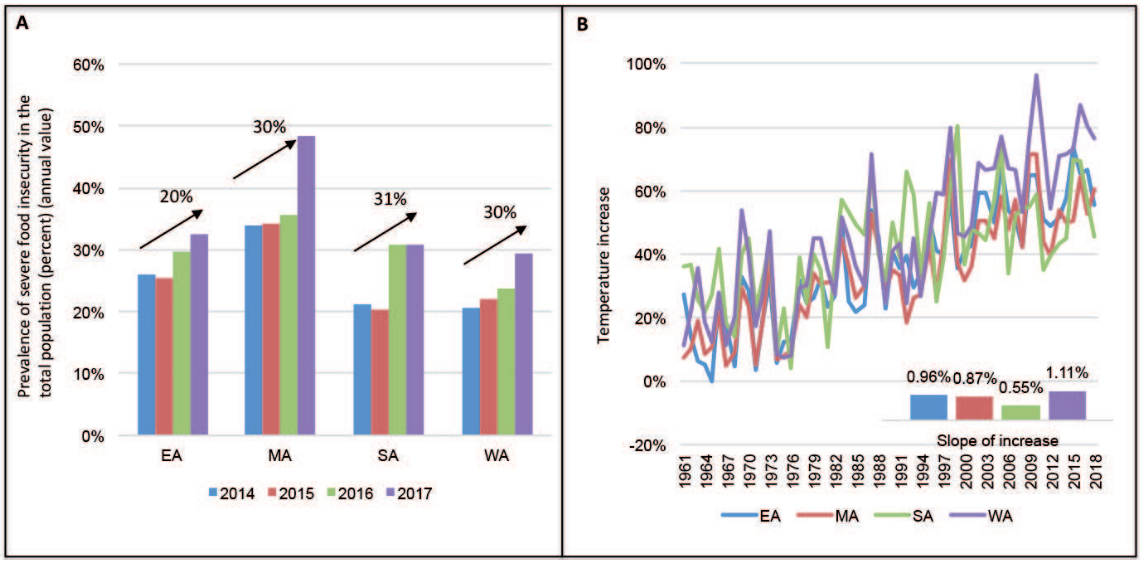


**Figure 5.**
*Temperature increase in all regions of SSA and the annual percentage of prevalence of severe food insecurity in the total population of each SSA region. Abbreviations: East Africa (EA), Middle Africa (MA), Southern Africa (SA), West Africa (WA) [7].*

The second most relevant farming system is the arid pastoral oasis farming system covering 62% of the arid AEZ and 40% of the West Africa region (**Table 1**). This farming system contains some oasis farming and a number of irrigation schemes, producing date palm (*Phoenix dactylifera* L.) and other palms, vegetables, and stable crops such as maize and rice [14].

This farming system is the most dependent on rainfall, and although West Africa has an annual temperature increase of 1.1% (**Figure 5B**), there is also a projection of 30–70% increased precipitation within semiarid and subhumid AEZs in West Africa [17] which account for 25 and 22% of the area, respectively, thus presenting a minor prevalence of severe food insecurity (**Figure 5A**). In the third place, there are two farming systems that have relevance in SSA, agropastoral and pastoral. Agropastoral farming system, generally in the semiarid and tropical highlands of East and South Africa (**Table 1**), is characterized by producing both crops and livestock. Approximately, 22 million ha are used for crops, mainly rainfed sorghum and pearl milted for family subsistence, whereas sesame and pulses are for household income. Livestock are also kept for subsistence (milk and milk products), offspring, transportation (camels, donkeys), land preparation (oxen, camels), income revenue, exchange, savings, bride wealth, and/or insurance against crop failure [14]. One of the major concerns and fragilities of this area is its vulnerability to drought, leading to crop failure and consequently to weaker animals due to a decrease in crop biomass production [19]. As animals are insurance to crop failure, severe drought leads to decapitalizations of herds and therefore lack of animals to exchange for grain. In addition, the search for more land, to mitigate the decrease in millet and sorghum yields for subsistence, along the investment in other crops used for trading (e.g., pulses) promotes a decline in soil fertility and weed infestation, mainly by *striga* in cereals. Prevalence of severe food insecurity has increased greatly in South Africa from 2016 to 2017 (**Figure 5A**), which is of great concern considering the alarming prediction of drought severity for South Africa [20].

The pastoral farming system, generally in the arid and subtropical AEZs, occupying 40.4% in South Africa region and 21% in East Africa, is dominated by livestock, where livelihoods depend mainly from cattle, camels, sheep, goats, some cereal crops, and off-farm work [21]. Being mostly present in arid regions and in

South Africa, the main source of vulnerability is the great climatic variability and consequently high incidence of drought, similarly to the agropastoral farming systems.

Overall, regardless of the farming system, the major concern of SSA food security is connected to drought, due to the dependency on the rainfall periods in most of the farming systems. As such, SSA farming system sustainability has been largely affected by climate changes, such as increases in temperature (**Figure 5A**) and the occurrence of 291 events of extreme drought [22], posing a clear threat to the maintenance of current and future crop production, affecting smallholder's livelihoods and food security in the long run. Increasing food production by expansion of agricultural land is fragile, as population grows, thus demanding more land through deforestation. FAO Special Programme for Food Security considers intensification of existing production patterns and diversification of production and processing, as the two main strategies to eradicate poverty and hunger. These two strategies meet the objective of sustainable intensification (SI) concepts, in combination with site-specific factors and agroecological conditions. SI is defined as the process of "producing more food from the same area of land while reducing the environmental impacts" [23]. Pretty et al. [24] stated that from 40 projects over 20 countries involving over 10 million farmers, SI increased farm productivity over twofold. Moreover, an adequate implementation of SI worldwide could respond to 2050 food demand while supporting land conservation from 1 to 0.2 billion ha and decreasing gasoline gallon equivalent (GGE) from 3 to 1 Gt per year [25]. Thus, it is imperative to emphasize and implement efficiently SI practices and agricultural technologies in SSA to ensure both food security and profitability. To sustainably increase yields of smallholders in their farming systems, it is essential to adopt an effective land management and implement strategies that aid farmers to face climate uncertainties.

### 2.1 Promoting sustainable crop production: the potential of multipurpose pulse crops

A sustainable crop production needs an efficient soil fertility management, in order to prospect future high yield production. Most African soils are poor compared to most other parts of the world, due to the lack of volcanic rejuvenation. This has caused African soils to undergo various cycles of weathering, erosion, and leaching, resulting in poor nutrient soils [26]. As the population continues to grow at a fasting rate leading to an increased demand for food, Africa's agricultural land is becoming increasingly degraded (**Figure 6A**), due to ill management practices and of external inputs. In East Africa the rate of depletion is so high that even drastic measures, such as doubling the application of fertilizer (**Figure 6B**) or manure or halving erosion losses, would not be enough to offset nutrient deficits. In African soil, there is higher depletion of nitrogen and potassium than phosphorus due to leaching and soil erosion. These soil problems are the result of continuous cropping of cereals without rotation with legumes, inappropriate soil conservation practices, and inadequate amounts of fertilizer use [28]. These problems are aggravated by short growing seasons together with limited water availability from rainfall resulting in restricted crop diversification contributing for additional pressure on the land.

Among all the plant nutrients essential for crop production, nitrogen is the key nutrient [29]. African farmers to fulfill this large nitrogen requirement for crop production in an increasing depleted soil are using 16 metric tons of nitrogen each year (**Figure 6B**) [7]. Pulse crops and soil microorganisms have potential to convert nitrogen into plant-usable forms, contributing significant amounts of nitrogen to

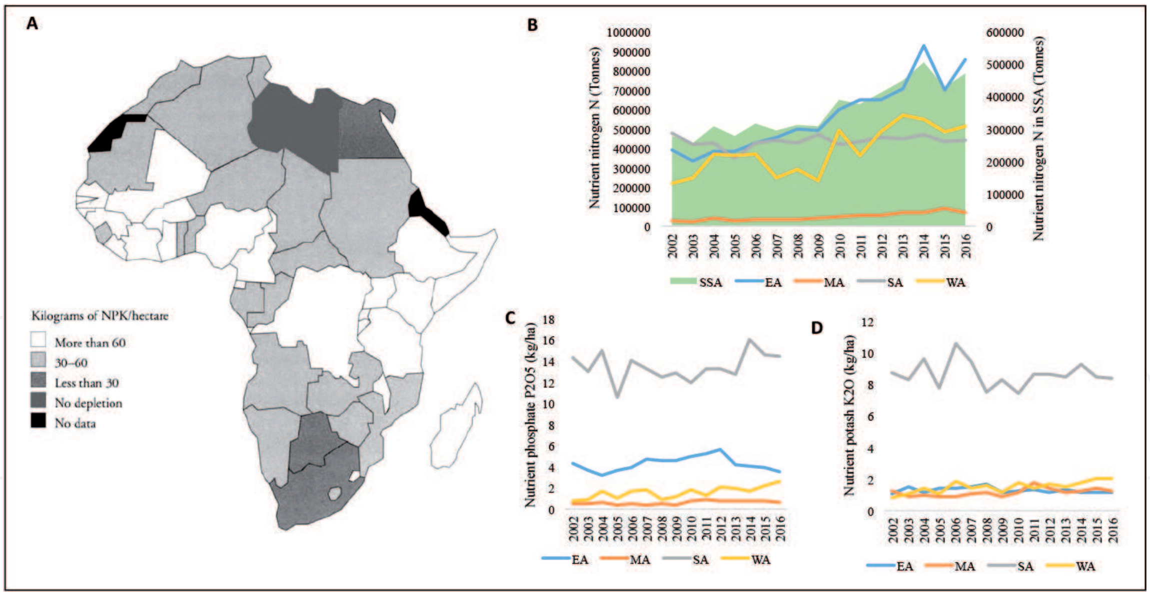


**Figure 6.**
*(A) Average annual nutrient depletion (NPK) in Africa, 1993–1995 [27]; (B) average of total nitrogen (N) from all fertilizer products; (C) average of total phosphate ($P_2O_5$) from all fertilizer products; (D) average of total potassium ($K_2O$) from all fertilizer products [7].*

satisfy crop needs. To respond population food needs, natural sources of nitrogen are not sufficient to achieve required yields; thus, there is a need to complement with chemical nitrogen but in an efficient, eco-friendly, and environmental management manner. Under current scenario, there is an urgent need for improving nitrogen use efficiency and balance use of natural resources which is essential for sustainable agricultural production [30]. Pulses, and especially multipurpose pulses, are part of Africa history due to their multiple benefits in agriculture and society. Multipurpose pulses serve and are needed for different functions and in general are best to respond to the diverse needs of farmers, including food, fuel, and fodder, and ecosystem services such as pollination and improving soil fertility and organic matter content. By increasing soil organic matter content, an improvement in soil structure is obtained, promoting an increase in water-holding capacity [31]. Moreover, pulses and legumes in general have the natural ability to biologically fix atmospheric nitrogen and to enhance the biological turnover of phosphorous [32]. However, over time, consumers' preferences have changed with traditional crops which have been replaced by staple crops (e.g., rice, cassava, and maize) and which have been subject to intensive research and political support worldwide. The quantity of arable land used for pulses is much less than the area cultivated with important cereals (**Figure 2B**), thus negatively affecting the nutrient balance in African soils [32]. Multipurpose pulse crops offer smallholder farmers a multifaceted way to improve food security, diet, and soil health as well as economic returns and income stability. SSA smallholder's farmers have been incentivized to produce common bean and cowpea (**Figure 7**), but with climate change and most of SSA agriculture being rainfall dependent, future is compromised. Although the production of cowpea (**Figure 7E**) and bean (**Figure 7F**) is far greater than other pulses (**Figure 7G**), the area distribution of pulses is more comprehensive within AEZ and farming systems, especially in the major SSA farming systems as maize mixed and agropastoral (**Figure 3B**). Thus, it is important to recover and enhance agriculture productivity of local crops, known as orphan legumes, known to local farmers and communities. Moreover, these orphan legumes are a likely source of important traits for introduction into major crops to aid in combating the stresses associated with global climate change.

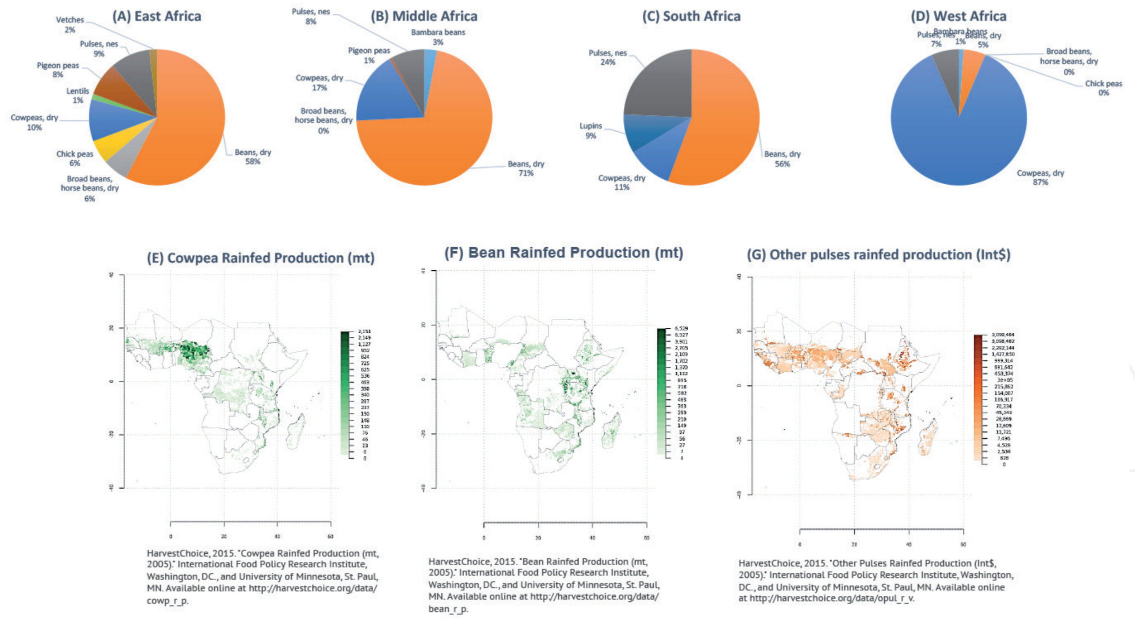


**Figure 7.**
*Area harvested of pulses in East Africa (A), Middle Africa (B), South Africa (C), and West Africa (D). Data retrieved from FAOSTAT (accessed March 2019). Rainfed production of cowpea (E) and beans (F) in metric tons (mt) for SSA. Rainfed production of other pulses in international dollars (Int$) for SSA [33–35].*

Thus, the potential use of multipurpose pulse crops as a sustainable strategy to overcome the present problems associated with the agricultural intensification is undeniable to cope soil depletion and decreasing crop yields annually, as well as inevitable environmental changes that will occur in the next 50 years. The promotion of neglected and underutilized species (NUS) African legumes adapted to rainfed and drought conditions will contribute not only to the diversity of cropping systems but also to decrease food insecurity. However, there is the need to address critical knowledge gaps that will allow the full use and advantages to introduce successfully pulse crops within agricultural and food systems. Part of this includes promoting pulse farming and implementing different farm management practices in order to contribute to the resilience of SSA farming systems. As the world celebrated the International Year of Pulses in 2016, there is a continuous need to establish the potential and invest in the innovation of undervalued role that pulses can play and that have to play in the post-2016 agenda.

## 3. Climate change and crop production in SSA: the key role of pulse crops

Changes in temperature and rainfall regime may have considerable impacts on agricultural productivity and on the ecosystem on which many people depend [36]. Rainfall amounts, distribution, and intensity are already producing floods, droughts, and changes in large-scale hydrological cycle [37, 38] which will affect the duration of crop growing seasons. Changes in temperatures affect plant growth and animal feed intake. Increases in maximum temperatures can lead to yield reductions and reproductive failure in maize, and animals reduce their feed intake. Maize being the most produced staple crops in SSA is particularly sensitive to temperatures above 30°C [17]. Also, wheat growing temperature is already above optimal, and it is expected to increase [39]. Increase in nighttime temperatures can also lead to decrease in rice yields, especially during the dry season. Another concerning factor is the increasing carbon dioxide concentration in the atmosphere that is beneficial for C3 plants such as wheat, but not for C4 plants such as maize and sorghum, and it may also decrease protein concentration in wheat grain, reducing nutrient availability for animals. Climate projections indicate losses of 27–32% for maize, millet, and groundnut [40] and 71% for beans [41] especially soybean that is the most common legumes produced.

Rainfed farming system in SSA produces 90% of staple food in SSA [42] and in the face of long periods of drought or dry spells in the growing season causes an unbalancing of the cycle of by-products in the mix farming system [43]. In order to find more suitable agriculture conditions, population migration takes place. This strategy, together with the increase in population, is leading to tropical rainforest destruction to conquer agriculture land, plus the general land degradation due to inappropriate land use, which in turn causes desertification, salinization, sodification, and soil and water erosion, increasing atmospheric carbon dioxide and creating a spiraling decline in the productivity of the land in terms of both food and other natural resources [14]. Projections are alarming; showing climate variability on agricultural production will have substantial effects in mixed smallholder systems, resulting in reduced food security that potentially increases the risk of hunger and undernutrition. However, it is the mixed system that presents the best capacity to tackle the inevitable change in climate. For that, farmers may have to respond by increasing the system resilience, diversification, and risk management [36]. To increase system resilience, farmers have to improve soil and nutrient management, through manure and crop residues, using, for example, legumes for natural nitrogen fixation and suitable for livestock feed. Also, they need to improve ecosystem management and biodiversity, by considering the substantial genetic variability in domestic crops and livestock that have the ability to withstand extreme temperatures, drought, and other environmental constrains, as well as pests and diseases. The combination of different crops and livestock breeds with their wild relatives is fundamental in developing a sustainable resilience [36].

Of the 400,000 plants species in existence today, only actinorhizal plants and legumes have evolved nitrogen-fixing nodules [44]. The primary role that legumes play is to fix atmospheric nitrogen through their symbiotic relationship with *Rhizobium* spp., contributing with nitrogenous compounds to the soil, either directly, by nodule excretion, or indirectly, by decomposition of root nodules and tissues [45]. The ability to fix atmospheric nitrogen makes legumes excellent partners within various farming systems, as they provide nitrogen and therefore reduce the needs for mineral nitrogen fertilizers by associated non-legumes [46].

The use of inorganic nitrogenous fertilizers has increased exponentially over the last 50 years, but just 30–50% of crop yields are sustained by inorganic fertilizers, although between 1960 and 2000, the efficiency of nitrogen for global cereal production decreased from 80 to 30%. Moreover, more than 50% of nitrogen fertilizer applied was lost from cereal crops between 1961 and 2010, and in some cases more than 80% is lost [46]. As a result there has been a 5% increase year by year of carbon dioxide equivalent emission [47]. These data show an unsustainable trend for African farmers. Increases of atmospheric carbon dioxide benefit cereal growth, and it decreases protein content in the grain, as opposite to what has been observed in cereal grains produced followed by legume crops. Therefore, intercropping or rotation of grain legumes with cereals or other non-leguminous crops increases nitrogen-use efficiency, reducing greenhouse gas emissions. It is estimated that grain legumes can offer 20–40% wheat nitrogen needs [48]; thus, intercropping is important for the development of sustainable systems, particularly in systems with limited external inputs [49]. About 21 Mt. of nitrogen is fixed annually by legume-rhizobia symbiosis, returning 5–7 Mt. of nitrogen to soils from about 190 million ha of grain legumes [48]. Without a doubt, cultivation of grain legumes is a very promising approach to increase farmers' income, especially when compared to cereal monoculture that was boosted by the "Green Revolution" [50]. Grain legumes are a very important food crop in many parts of Africa, as they are a source of nitrogen-rich edible seeds, providing high-protein products. Grain legume yields vary more than staple crops, mostly due to environmental constrains such as drought that limits symbiotic nitrogen fixation [51, 52], which in turn diminishes nutrient grain quality [53]. Soybean has clearly dominated yields, with increases of 2.9% year by year, whereas cowpea yield is stable but occupying 4.3% more land every year, trying to minimize the loss to diseases as well as insect pests and drought, low soil fertility, other abiotic stresses, and low availability of seed of improved varieties [47].

There is fast evidence that intercropping and rotation with grain legumes are beneficial as legumes improve soil structure, increase organic matter [54, 55], and provide food and feed to the most widespread farming system in Africa, the mixed-crop-livestock farming system. Moreover, intercropping or rotation with grain legumes improves water efficiency by saving water for subsequent crops or by providing soil coverage, minimizing soil evaporation, erosion, and weeds, which makes feasible the production of grain legumes in dry, drought-vulnerable, and low-labor availability areas. Residue from grain legumes provides an excellent source of high-quality feed to livestock especially during the dry season, when animal feeds are in short supply. Synergies between crops and livestock offer various opportunities for raising productivity and increasing efficiency of resources, thus increasing household incomes and securing availability and access to food [36]. Moreover, the residues from grain legume cultivation will preserve soil moisture, prevent soil erosion, and increase yields in the same piece of land, which are all big constraints of SSA farming systems that are constantly facing anthropic pressure.

Farmers have been neglecting these native grain legumes, as they are incentivized to produce common bean and soybean. However, with climate change and most of SSA agriculture being rainfall dependent, future is compromised. Many grain legume breeding programs are suffering from low genetic diversity and several bottlenecks that occurred during and after domestication. Thus, it is vital to consider the considerable large genetic variability in native crops that have the ability to withstand extreme temperatures, drought, and other environmental constrains. In agricultural statistics *Lablab*, jack, or sword bean (*Canavalia* spp.), winged bean (*Psophocarpus tetragonolobus* DC), guar bean (*Cyamopsis tetragonoloba* Taub.), velvet bean (*Stizolobium* spp.), yam bean (*Pachyrhizus erosus* Urb.), and others are recognized worldwide as "minor crops," pooled in "Pulses, nes" (pulses that are not identified separately, according to FAO). However, these pulses have been showing a steady but modest yield increase over the last 50 years, without occupying more land [7] (**Figure 1**).

### 3.1 The role of orphan legumes for the crop production sustainability of SSA farming systems

There is a lack of consensus in the definition and what orphan or neglected and underutilized species (NUS) should be referred to. These crops have been referred by different names, such as orphan crops, neglected crops, underutilized crops, forgotten crops, and minor crops. In this study we will refer this group as NUSs, under the definition of plants with prospective value as crops but which have been paid limited attention by agricultural researchers, plant breeders, seed companies, and policymakers [56]. However, due to the potential that these crops hold as food, nutritional content, and economic security of the developing and undeveloped parts of the world, they are appropriately referred to as crops for the future [57]. As such, these crops represent an opportunity for innovation in research, capacity building, social empowerment, and food value chains (i.e., production, processing, consumption, marketing, and product development). Understanding the importance that these crops hold, the African Orphan Crop Consortium (AOCC) was established with the full support of the African Union in 2011, assigned to work on 101 selected crops originated or naturalized in Africa (http://africanorphancrops.org) by investing in training, products, tools, services, practices, and processes to mainstream them into the African agro-food system [58]. In conjunction with this initiative, the FAO builds the database named International Network of Food Data Systems (INFOODS) listing more than 1000 unique NUS (http://www.fao.org/fileadmin/templates/food_composition/documents/Copy_of_INFOODS-List-of-underutilized-species-2_0_Jan15.xls). The AOCC partnership works to make high-nutritional-value crops grown by African farmers available to rural and urban consumers by promoting the adoption of modern breeding methods for crop improvement purposes. Under these pillars, genomic resources through next-generation sequencing from the collection of 101 African NUS are being generated (see http://africanorphancrops.org/meet-the-crops/), which included important annual and perennial (tree) species, e.g., *Moringa oleifera* L. known as the tree of life and the iconic boabab tree (*Adansonia digitata* L.). Through the high-throughput genomic resources gathered, the AOCC is also engaged to develop tools to assess genetic diversity in crops and to support breeding programs. Among such NUSs, there are several pulse crops (**Table 2**), and with the high genomic data generated, it will enable to promote research and breeding studies on the crops that will open a new venue toward understanding its suitability on several farming systems.

Lablab [*Lablab purpureus* (L.) Sweet] and velvet [*Mucuna pruriens* (L.) DC] beans are among the selected NUSs, which are known to display agronomic, nutritional, and versatile characteristics, and thus can be faced as important examples of multipurpose legumes that could and should be integrated in the most representative African farming systems, maize mixed and the agropastoral farming systems. Studies have reported that crude protein concentration in maize silage increases when intercropping with *Lablab* without compromising forage yield or milk production [59] and dry matter yield [60]. *Lablab*, locally called *njahe*, has a special significance and is intimately associated with women fertility [61] probably due to its abundance in palmitic acid [62], a fatty acid that has a structural and functional role in utero [63]. Being women the cornerstone of African economic development, contributing with approximately 70% of agricultural labor and produce about 90% of all food [47], the interest in boosting *Lablab* and other NUC legumes development is key for diversifying agriculture sector [64]. It is estimated that grain legumes increase wheat productivity by 77% and of maize by 25–33%. An intercrop system of maize with common bean resulted in maize with higher biomass yield, plant total nitrogen concentration, and crude protein concentration [65]. Intercropping maize and soybean was shown to be beneficial, as there was an increase of 19–36% in crude protein over monoculture corn [66]. Intercrop of maize with cowpea increased 9% in crude protein compared with monoculture corn [67], adding that cowpea nitrogen fixation under drought conditions is highly tolerant [68]. Also, pigeon pea (*Cajanus cajan*) is another legume mainly grown by poor farmers and is known as the poor people's meat because of its high protein content. It is among the most drought-tolerant and nutritious orphan legume crops and withstands drought because of its deep roots and osmotic adjustment in the leaves [69].

Finally, the characterization of orphan legumes on the "omics" level is still starting, and these legumes remain unexplored on the genomic, transcriptomic, and proteomic level, despite the efforts such as the African Orphan Crops Initiative (http://africanorphancrops.org), which are starting to fill the genomic information gap.

| Scientific name | Common name | Assembled | Stages of assembly | Ref. |
|---|---|---|---|---|
| *Artocarpus heterophyllus* | Jack tree | | Reference genome | [58] |
| *Artocarpus altilis* | Breadfruit | | Reference genome | [58] |
| *Faidherbia albida* | Acacia (apple ring) | Reference genome | | [69] |
| *Moringa oleifera* | Drumstick tree | Reference genome | | [69] |
| *Sclerocarya birrea* | Marula | Reference genome | | [69] |
| *Digitaria exilis* | Fonio | | Reference genome | [58] |
| *Eleusine coracana* | Finger millet | | Reference genome | [58] |
| *Lablab purpureus* | *Lablab* bean | Reference genome | | [70] |
| | | RNAseq | | [71] |
| *Solanum aethiopicum* | African eggplant | Reference genome | | [72] |
| *Vigna subterranea* | Bambara groundnut | Reference genome | | [70] |
| | | RNAseq | | [71] |
| *In the pipeline or soon: Abelmoschus caillei; Adansonia digitata; Allanblackia floribunda; Allanblackia stulhmannii; Allium cepa; Amaranthus cruentus; Amaranthus tricolor; Anacardium occidentale; Annona reticulata; Annona senegalensis; Balanites aegyptiaca; Basella alba; Boscia senegalensis; Brassica carinata; Canarium madagascariense; Carica papaya; Carissa spinarum; Casimiroa edulis; Cassia obtusifólia; Celosia argentea; Chrysophyllum cainito; Citrullus lanatus; Cleome gynandra; Cocos nucífera; Colocasia esculenta; Corchorus olitorius; Crassocephalum rubens; Crotalaria juncea; Crotalaria ochroleuca; Cucumis metuliferus; Cucurbita maxima; Cyphomandra betacea; Dacryodes edulis; Detarium microcarpum; Detarium senegalense; Dioscorea alata; Dioscorea dumetorum; Dioscorea rotundata; Diospyros mespiliformis; Dovyalis caffra; Ensete ventricosum; Eragrostis tef; Garcinia livingstonii; Garcinia mangostana; Gnetum africanum; Hibiscus sabdariffa; Icacina oliviformis; Ipomoea batatas; Irvingia gabonensis; Landolphia spp.; Lannea microcarpa; Lens culinaris; Macadamia ternifólia; Macrotyloma geocarpum; Mangifera indica; Momordica charantia; Morus alba; Musa acuminata AAA Group; Musa balbisiana; Opuntia monacantha; Parinari curatellifolia; Parkia biglobosa; Passiflora edulis; Persea americana; Phaseolus vulgaris; Plectranthus esculentus; Plectranthus rotundifolius; Psidium guajava; Ricinodendron heudelotii; Saba comorensis; Saba senegalensis; Solanum scabrum; Sphenostylis stenocarpa; Strychnos cocculoides; Strychnos spinosa; Syzygium guineense; Talinum fruticosum; Tamarindus indica; Telfairia occidentalis; Tylosema esculentum; Uapaca kirkiana; Vangueria infausta; Vangueria madagascariensis; Vicia faba; Vigna radiata; Vitellaria paradoxa; Vitex doniana; Xanthosoma sagittifolium; Xanthosoma spp.; Ximenia caffra; Ziziphus mauritiana* | | | | |

**Table 2.**
*Present status and progress of AOCC developing genomic resources—reference genome sequencing of 100 accessions/species for 101 crops [58].*

## 4. Final remarks

In sub-Saharan Africa, countries rely mostly on agriculture as economic revenue and as a base for smallholder farmers, for both household income and food. Considering the diversity of the farming systems along the different agroecological zonings, evaluating its performance under climate changes is key to determine its future sustainability for alleviating poverty and food security. Overall, major farming systems in SSA are under threat since they are rainfall-dependent and thus pose a scenario of food insecurity if no proper agriculture management and solutions are taken. In this chapter, the potential of pulse crops as a viable and sustainable strategy for upholding farming systems' intercropping and production indices was highlighted. The promotion of legumes adapted to semi- and arid conditions will contribute to the diversity of cropping systems and diets of African people living in rural areas. However, there is a need to address critical knowledge gaps that will allow the full use and advantages to introduce successfully the so-called neglected and underutilized crops, native to Africa, within agricultural and food systems. By exploring native legumes adapted to arid conditions, namely, low rainfall periods, it will be a key tool for adaptation to climate change. This will also contribute to improve soil fertility and enhance food, forage, and mulching quality, which is of main importance particularly for the developing countries. Therefore, promoting its cultivation and implementing different farm management practices will contribute to the resilience of SSA farming systems. As the world celebrated the International Year of Pulses in 2016, there is a need to establish the potential and invest in the innovation of undervalued role that pulses can play in the post-2016 agenda. In spite of their recognized importance, some African native legumes are still underutilized or overlooked crops, and its use is a viable option to raise farming productivity.

## Acknowledgements

The work was funded by the Portuguese Rural Development Program (PDR2020) for the Operational Group STEnCIL, Initiative 27 [PDR2020–1.0.1-FEADER-031465], within the European Innovation Partnership (EIP-AGRI) supported by the European Agricultural Fund for Rural Development and undertaken in the scope of project CajOmics [PTDC/AGR-PRO/5727/2014] funded by the Fundação para a Ciência e Tecnologia (FCT)-FCT/MCTES/PIDDAC, Portugal, and the project CVAgrobiodiversity/333111699 funded by the Fundação para a Ciência e Tecnologia (FCT) and Aga Khan Development Network (AKDN). The work was supported by FCT funds, to the following research units: LEAF [UID/AGR/04129/2019] and cE3c [UID/BIA/00329/2019]. FM was individually funded by FCT-awarded postdoctoral fellowship SFRH/BPD/115162/2016.

## Conflict of interest

The authors declare no conflict of interest.

## Author details

Patricia Vidigal[1], Maria Manuel Romeiras[1,2] and Filipa Monteiro[1,2]*

1 Linking Landscape, Environment, Agriculture and Food (LEAF), Instituto Superior de Agronomia, Universidade de Lisboa, Lisboa, Portugal

2 Faculdade de Ciências, Centre for Ecology, Evolution and Environmental Changes (cE3c), Universidade de Lisboa, Lisboa, Portugal

*Address all correspondence to: fimonteiro@fc.ul.pt; fmonteiro@isa.ulisboa.pt

## References

[1] Grönemeyer JL, Reinhold-Hurek B. Diversity of bradyrhizobia in subsahara Africa: A rich resource. Frontiers in Microbiology. 2018;**9**. DOI: 10.3389/fmicb.2018.02194. Epub ahead of print 20 September 2018

[2] FAO. World Food and Agriculture—Statistical Pocketbook 2018. Rome, Italy: FAO; 2018. p. 255

[3] Monteiro F, Catarino L, Batista D, Indjai B, Duarte MC, Romeiras MM. Cashew as a High Agricultural Commodity in West Africa: Insights towards Sustainable Production in Guinea-Bissau. Sustainability. 2017;**9**:1666. https://doi.org/10.3390/su9091666

[4] Havik PJ, Monteiro F, Catarino S, Correia AM, Catarino L, Romeiras MM. Agro-Economic Transitions in Guinea-Bissau (West Africa): Historical Trends and Current Insights. Sustainability. 2018;**10**:3408. https://doi.org/10.3390/su10103408

[5] FAO. State of Food and Agriculture in the Region, Including Future Prospects and Emerging Issues. In: Regional Conference for Europe. Food and Agriculture Organization of the United Nations; 2014. p. 15

[6] Djurfeldt AA, Jirström M. Urbanization and Changes in Farm Size in Sub-Saharan Africa and Asia from a Geographical Perspective: A Review of the Literature. CGIAR's Independent Science and Partnership Council; 2013. pp. 1-40

[7] FAO. Food and Agriculture Organization of the United Nations. 2019. Available from: http://www.fao.org/faostat/en/ [Accessed: 12 April 2019]

[8] Blackie M, Malcom J. Maize, food self-sufficiency and policy in East and Southern Africa. Food Policy. 1990;**15**:383-394. DOI: 10.1016/0306-9192(90)90055-5

[9] Byerlee D, Eicher CK, editors. Africa's Emerging Maize Revolution. Boulder, London: Lynne Rienner; 1997. 301 p. ISBN: 1-55,587-776-1

[10] Mellor, John W, Delgado C, et al. Accelerating food production in sub-Saharan Africa. In: Agricultural Development. Baltimore: Johns Hopkins; 1987. 417 p

[11] Catarino S, Duarte MC, Costa E, et al. Conservation and sustainable use of the medicinal leguminosae plants from Angola. Peer Journal. 2019;7:e6736. DOI: 10.7717/peerj.6736

[12] HarvestChoice. AEZ Tropical (5-class, 2009). Washington, DC, and University of Minnesota, St. Paul, MN: International Food Policy Research Institute; 2015. Available from: http://harvestchoice.org/data/aez5_clas. [Accessed: 21 April 2019]

[13] HarvestChoice. Farming System Name. International Washington, DC, and University of Minnesota, St. Paul, MN: Food Policy Research Institute; 2015. Available from: http://harvestchoice.org/data/fs_2012_tx [Accessed: 21 April 2019]

[14] Dixon J, Gulliver A, Gibbon D. Sub-Saharan Africa. In: Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World. Rome and Washington DC: FAO and World Bank; 2001. 412 p

[15] HarvestChoice. Food Crops Irrigated Value Production (Int$, 2005). Washington, DC, and University of Minnesota, St. Paul, MN: International Food Policy Research Institute; 2015. Available from: http://harvestchoice.org/data/vp_food_i [Accessed: 21 April 2019]

[16] HarvestChoice. Food Crops Rainfed Value Production (Int$, 2005). Washington, DC, and University of Minnesota, St. Paul, MN: International Food Policy Research Institute; 2015. Available from: http://harvestchoice.org/data/vp_food_r [Accessed: 21 April 2019]

[17] Serdeczny O, Adams S, Baarsch F, et al. Climate change impacts in sub-Saharan Africa: From physical changes to their social repercussions. Regional Environmental Change. 2017;**17**:1585-1600. DOI: 10.1007/s10113-015-0910-2

[18] Shiferaw B, Prasanna BM, Hellin J, et al. Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. Food Security. 2011;**3**:307-327. DOI: 10.1007/s12571-011-0140-5

[19] Masike S, Ulrich P. Vulnerability of traditional beef sector to drought and the challenges of climate change: The case of Kgatleng district, Botswana. Journal of Geography and Regional Planning. 2008;**1**:12-18

[20] Tian-Jun Z, Tao H. Projected changes of palmer drought severity index under an RCP8.5 scenario. Atmospheric and Oceanic Science Letters. 2013;**6**:273-278. DOI: 10.3878/j.issn.1674-2834.13.0032

[21] Garrity D, Dixon J, Boffa JM. Understanding African Farming Systems: Science and Policy Implications. 2012. Available from: http://aciar. gov. au/aifsc/sites/default/files/images/understanding_african_farming_systems_11_dec_update. pdf

[22] Masih I, Maskey S, Mussá FEF, et al. A review of droughts on the African continent: A geospatial and long-term perspective. Hydrology and Earth System Sciences. 2014;**18**:3635-3649. DOI: 10.5194/hess-18-3635-2014

[23] Godfray HCJ, Beddington JR, Crute IR, et al. The challenge of food security. Science. 2012;**327**:812. DOI: 10.4337/9780857939388

[24] Pretty J, Toulmin C, Williams S. Sustainable intensification in African agriculture. International Journal of Agricultural Sustainability. 2011;**9**:5-24. DOI: 10.3763/ijas.2010.0583

[25] Tilman D, Balzer C, Hill J, et al. Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences. 2011;**108**:20260-20264. DOI: 10.1073/pnas.1116437108

[26] Smaling EM. The balance may look fine when there is nothing you can mine: Nutrient stocks and flows in West African soils. In: Gerner H, Mokwunye AU, editors. Use of Phosphate Rock for Sustainable Agriculture in West Africa; 21-23 November 1995; IFDC-Africa; 1995

[27] Henao J, Baanante C. Nutrient depletion in the agricultural soils of Africa. In: Pinstrup-Andersen P, Pandya-Lorch R, editors. The Unfinished Agenda: Perspectives on Overcoming Hunger, Poverty, and Environmental Degradation. Washington, D.C: IFPRI; 2001. p. 301

[28] Bationo A, Hartemink A, Lungu O, et al. Knowing the African soils to improve fertilizer recommendations. In: Improving Soil Fertility Recommendations in Africa using the Decision Support System for Agrotechnology Transfer (DSSAT). Dordrecht: Springer Netherlands; 2012. pp. 19-42

[29] Mosier AR, Bleken MA, Chaiwanakupt P, et al. Policy implications of human-accelerated nitrogen cycling. Biogeochemistry. 2001;**52**:281-320. DOI: 10.1023/A:1015798424363

[30] Yadav MR, Kumar R, Parihar CM, et al. Strategies for improving nitrogen

use efficiency: A review. Agricultural Reviews. DOI: 10.18805/ag.v0iOF.7306. Epub ahead of print 16 February 2017

[31] Pimentel D, Hepperly P, Hanson J, et al. Environmental, energetic, and economic comparisons of organic and conventional farming systems. Bioscience. 2005;**55**:573-582. DOI: 10.1641/0006-3568(2005)055[0573:EEAECO]2.0.CO;2

[32] Snapp S, Rahmanian M, Batello C. Pulse Crops for Sustainable Farms in Sub-Saharan Africa. Rome: FAO; 2018. Available from: http://www.fao.org/3/i8300en/I8300EN.pdf

[33] HarvestChoice. Cowpea Rainfed Production (mt, 2005). Washington, DC, and University of Minnesota, St. Paul, MN: International Food Policy Research Institute; 2015. Available from: http://harvestchoice.org/data/cowp_r_p [Accessed: 21 April 2019]

[34] HarvestChoice. Bean Rainfed Production (mt, 2005). Washington, DC, and University of Minnesota, St. Paul, MN: International Food Policy Research Institute; 2015. Available from: http://harvestchoice.org/data/bean_r_p. [Accessed: 21 April 2019]

[35] HarvestChoice. Other Pulses Rainfed Production (Int$, 2005). Washington, DC, and University of Minnesota, St. Paul, MN: International Food Policy Research Institute; 2015. Available from: http://harvestchoice.org/data/opul_r_v. [Accessed: 21 April 2019]

[36] Thornton PK, Herrero M. Adapting to climate change in the mixed crop and livestock farming systems in sub-Saharan Africa. Nature Climate Change. 2015;**5**:830-836. DOI: 10.1016/j.gfs.2014.02.002

[37] Dai A. Drought under global warming: A review. Wiley Interdisciplinary Reviews: Climate Change. 2011;**2**:45-65. DOI: 10.1002/wcc.81

[38] IPCC. Summary for policymakers. In: Climate Change 2014, Mitigation of Climate Change. Climate Change 2014 Synthesis Report Summary for Policymakers. 2014. Available from: https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_SPM.pdf

[39] Liu J, Fritz S, van Wesenbeeck CFA, et al. A spatially explicit assessment of current and future hotspots of hunger in sub-Saharan Africa in the context of global change. Global and Planetary Change. 2008;**64**:222-235. DOI: 10.1016/j.gloplacha.2008.09.007

[40] Schlenker W, Lobell DB. Robust negative impacts of climate change on African agriculture. Environmental Research Letters. 2010;**5**:014010. DOI: 10.1088/1748-9326/5/1/014010

[41] Thornton PK, Jones PG, Ericksen PJ, et al. Agriculture and food systems in sub-Saharan Africa in a 4 C+ world. Philosophical Transactions of the Royal Society A—Mathematical Physical and Engineering Sciences. 2011;**369**:117-136. DOI: 10.1098/rsta.2010.0246

[42] Rosegrant M, Cai X, Cline S. World Water and Food for 2025: Dealing with Scarcity. IFPRI: Washington, D.C; 2002. Available from: http://www.ifpri.org/themes/impact/impactwater.pdf

[43] Mohammed-Saleem MA. Mixed farming systems in sub-Saharan Africa. In: Wilson RT, Ehui S, Mack S, editors. Livestock Development Strategies for Low Income Countries—Proceedings of the Joint FAO/ILRI Roundtable on Livestock Development Strategies, for Low Income Countries, ILRI, Addis Ababa, Ethiopia. Nairobi, Kenya: Food and Agriculture Organization/International Livestock Research Institute; 1995

[44] Ribeiro-Barros AI, Catarino S, Moura I, et al. Actinorhizal trees and shrubs from Africa: Distribution, conservation and uses. Antonie Van Leeuwenhoek. 2019;**112**:31-46. DOI: 10.1007/s10482-018-1174-x

[45] Tothill JC. The role of legumes in farming systems of sub-Saharan Africa. In: Potential of Forage Legumes in Farming Systems of sub-Saharan Africa. Proceedings of a workshop held at ILCA; 16-19 September 1985. Ethiopia: Addis Ababa; 1986

[46] Foyer CH, Lam HM, Nguyen HT, et al. Neglecting legumes has compromised human health and sustainable food production. Nature Plants. 2016;**2**:16112. DOI: 10.1038/nplants.2016.112

[47] FAO. The Future of Food and Agriculture—Trends and Challenges. 2017. Available from: http://www.fao.org/3/a-i6583e.pdf

[48] Reeves TG, Thomas G, Ramsay G. Save and Grow in Practice Maize, Rice, Wheat. A Guide to Sustainable Cereal Production. Rome: Food and Agriculture Organization of the United Nations; 2016. Available from: www.fao.org/3/a-i4009e.pdf

[49] Adesogan AT, Salawu MB, Deaville ER. The effect on voluntary feed intake, in vivo digestibility and nitrogen balance in sheep of feeding grass silage or pea–wheat intercrops differing in pea to wheat ratio and maturity. Animal Feed Science and Technology. 2002;**96**:161-173. DOI: 10.1016/S0377-8401(01)00336-4

[50] Chibarabada T, Modi A, Mabhaudhi T. Expounding the value of grain legumes in the semi- and arid tropics. Sustainability. 2017;**9**:60. DOI: 10.3390/su9010060

[51] Devi MJ, Sinclair TR, Beebe SE, et al. Comparison of common bean (*Phaseolus vulgaris* L.) genotypes for nitrogen fixation tolerance to soil drying. Plant and Soil. 2013;**364**:29-37. DOI: 10.1007/s11104-012-1330-4

[52] Sinclair TR, Messina CD, Beatty A, et al. Assessment across the United States of the benefits of altered soybean drought traits. Agronomy Journal. 2010;**102**:475. DOI: 10.2134/agronj2009.0195

[53] Farooq M, Gogoi N, Barthakur S, Baroowa B, Bharadwaj N, Alghamdi SS, et al. Drought stress in grain legumes during reproduction and grain filling. Journal of Agronomy and Crop Science. 2017;**203**:81-102. DOI: 10.1111/jac.12169

[54] Courty PE, Smith P, Koegel S, et al. Inorganic nitrogen uptake and transport in beneficial plant root-microbe interactions. CRC Critical Reviews in Plant Sciences. 2015;**34**:4-16. DOI: 10.1080/07352689.2014.897897

[55] Peix A, Ramírez-Bahena MH, Velázquez E, et al. Bacterial associations with legumes. CRC Critical Reviews in Plant Sciences. 2015;**34**:17-42. DOI: 10.1080/07352689.2014.897899

[56] Padulosi S, Thompson J, Rudebjer P. Fighting Poverty, Hunger and Malnutrition with Neglected and Underutilized Species (NUS): Needs, Challenges and the Way Forward. Rome: Bioversity International; 2013

[57] Baldermann S, Blagojević L, Frede K, et al. Are neglected plants the food for the future? CRC Critical Reviews in Plant Sciences. 2016;**35**:106-119. 56p

[58] Hendre PS, Muthemba S, Kariba R, et al. African Orphan Crops Consortium (AOCC): Status of developing genomic resources for African orphan crops. Planta. DOI: 10.1007/s00425-019-03156-9. Epub ahead of print 9 May 2019

[59] Armstrong KL, Albrecht KA, Lauer JG, et al. Intercropping corn

with lablab bean, velvet bean, and Scarlet Runner bean for forage. Crop Science. 2008;**48**:371. DOI: 10.2135/cropsci2007.04.0244

[60] Contreras-Govea FE, Muck RE, Armstrong KL, et al. Fermentability of corn-lablab bean mixtures from different planting densities. Animal Feed Science and Technology. 2009;**149**:298-306. DOI: 10.1016/j.anifeedsci.2008.05.009

[61] Robertson CC. Black, white, and red all over: Beans, women, and agricultural imperialism in twentieth-century Kenya. Agricultural History. 1997;**71**:259-299. Available from: http://www.jstor.org/stable/3744315

[62] Vidigal P, Duarte B, Cavaco AR, et al. Preliminary diversity assessment of an undervalued tropical bean (*Lablab purpureus* (L.) Sweet) through fatty acid profiling. Plant Physiology and Biochemistry. 2018;**132**:508-514. DOI: 10.1016/j.plaphy.2018.10.001

[63] Agostoni C, Moreno L, Shamir R. Palmitic acid and health: Introduction. Critical Reviews in Food Science and Nutrition. 2016;**56**:1941-1942. DOI: 10.1080/10408398.2015.1017435

[64] Miller NR, Mariki W, Nord A, et al. Cultivar selection and management strategies for *Lablab purpureus* (L.) Sweet in Africa. In: Handbook of Climate Change Resilience. Cham: Springer International Publishing; 2018. pp. 1-14

[65] Dawo MI, Wilkinson JM, Sanders FE, et al. The yield and quality of fresh and ensiled plant material from intercropped maize (*Zea mays*) and beans (*Phaseolus vulgaris*). Journal of the Science of Food and Agriculture. 2007;**87**:1391-1399. DOI: 10.1002/jsfa.2879

[66] Herbert SJ, Putnam DH, Poos-Floyd MI, et al. Forage yield of intercropped corn and soybean in various planting patterns 1. Agronomy Journal. 1984;**76**:507. DOI: 10.2134/agronj1984.00021962007600040001x

[67] Bryan WB, Materu MB. Intercropping maize with climbing beans, cowpeas and velvet beans. Journal of Agronomy and Crop Science. 1987;**159**:245-250. DOI: 10.1111/j.1439-037X.1987.tb00096.x

[68] Sinclair TR, Manandhar A, Belko N, et al. Variation among cowpea genotypes in sensitivity of transpiration rate and symbiotic nitrogen fixation to soil drying. Crop Science. 2015;**55**:2270. DOI: 10.2135/cropsci2014.12.0816

[69] Odeny DA. The potential of pigeon pea (*Cajanus cajan* (L.) Millsp.) in Africa. Natural Resources Forum. 2007;**31**:297-305

[70] Chang Y, Liu H, Liu M, et al. The draft genomes of five agriculturally important African orphan crops. Gigascience. DOI: 10.1093/gigascience/giy152. Epub ahead of print 7 December 2018

[71] Chapman M. Transcriptome sequencing and marker development for four underutilized legumes. Applications in Plant Sciences. 2015;**3**:1400111. DOI: 10.3732/apps.1400111

[72] Song B, Song Y, Fu Y, et al. Draft genome sequence of the *Solanum aethiopicum* provides insights into disease resistance, drought tolerance and the evolution of the genome. bioRxiv. DOI: 10.1101/532077. Epub ahead of print 2019