Hindawi
International Journal of Agronomy
Volume 2020, Article ID 8833872, 14 pages
https://doi.org/10.1155/2020/8833872

Review Article

Soy-Maize Crop Rotations in Sub-Saharan Africa: A Literature Review

Liana Acevedo-Siaca[1] and Peter D. Goldsmith[2]

[1]*Department of Crop Sciences, University of Illinois, Champaign, USA*
[2]*Department of Agricultural and Consumer Economics, University of Illinois, Champaign, USA*

Correspondence should be addressed to Peter D. Goldsmith; pgoldsmi@illinois.edu

Received 26 June 2020; Revised 23 July 2020; Accepted 30 July 2020; Published 27 August 2020

Academic Editor: Wei Wu

Empirical evidence shows complementarity between maize and soybean as a sustained agricultural system across North and South America as well as Eastern Europe. The potential application to sub-Saharan Africa motivates this literature review. Maize is one of the most important crops on the African subcontinent, accounting for over half of daily caloric intake in some regions. However, continuous cropping of maize has led to extensive degradation of soil and decrease in crop productivity and endangers household food and nutritional security. The cultivation of soybean holds great promise in improving agricultural systems in sub-Saharan Africa. Introducing soy into rotation with maize is a method to diversify diets, better nutritional status, reduce abiotic and biotic stresses, and improve soil fertility, while enhancing crop productivity and generating more income for farmers. However, limited access to extension services and other sources of technical support constrains adoption of the more complex rotation cropping system involving a new crop, soybean. Rotating soybean with maize too challenges farmers as there is not a specific prescription that can guide farmers operating across Africa's diverse agroecological environments. Finally, soybean is an input-intensive crop requiring significant investment at planting, which may not allow small holders with limited resources and no access to credit.

1. Introduction

By the year 2050, sub-Saharan Africa (SSA) is expected to account for 22% of the global population due to high population growth rates [1]. Despite persistent food insecurity, great progress has been made in reducing hunger in SSA, with rates of hunger dropping from 33% to 23% between 1990 and 2016 [1]. Additionally, the prevalence of conditions caused by malnutrition, such as stunting and wasting, has decreased substantially [2–4]. However, SSA still exhibits the greatest food security risk of any developing region in the world and accounts for 38% and 27% of global child stunting and wasting, respectively [1, 5, 6]. Worryingly, the number of people expected to be food-insecure in the future is projected to increase as a result of continued population growth [1]. As a result, it is imperative that steps are taken to improve food security in SSA to keep pace with the growing population in the future.

Low crop productivity is one of the largest problems facing agriculture in SSA with staple crops only realizing a fraction of their yield potential [7–10]. In SSA, smallholder farmers produce 80% of the agricultural output, many of whom are wholly dependent upon agriculture for their livelihoods [11]. Large-scale, market-driven agricultural operations are not widespread in the African subcontinent and are only present in some regions, such as South Africa [1]. Due to limited access to farming resources, poor smallholder farmers are more likely to farm poor quality soil and are often plagued by low crop yields [7, 12]. Low crop productivity can also be exacerbated by the larger economic and political climate [6, 13]. Factors, particularly relevant to a commercial crop like soybean, such as poor infrastructure, limited access to markets and technical assistance, barriers to acquiring agricultural inputs, pervasive rural poverty, uncertain land tenure, and poor policy enactment can all negatively impact crop productivity in SSA [1, 6, 10, 13, 14].

There may be an opportunity to improve crop productivity in SSA through the implementation of soy-maize rotations as a form of agricultural intensification. Empirical evidence shows complementarity between maize and soybean as a sustained agricultural system across North and South America as well as Eastern Europe geographies and within temperate, subtropical, and tropical agroecologies. The research on the subject within SSA presents clear technical evidence of the positive results from rotating soybean with maize. Yet adoption in sub-Saharan Africa remains limited. Understanding this conundrum of clear benefits, weak adoption of maize-soybean rotation systems yet motivates this literature review. Secondly, the analysis of the literature will also yield the necessary research needed to close the adoption gap between producers in sub-Saharan Africa and the rest of the world.

Currently, the literature largely considers the benefits and implementation of soy-maize rotations in SSA at the discipline and single variable level, as opposed to a system or multivariate approach. For example, a work, as far back as 1988 [15], shows how effective a maize-soybean rotation can be reducing the severe yield losses to maize from the parasitic weed Striga. Yet continuous maize systems persist, and significant economic losses from Striga persist.

This review (within the context of SSA) (i) gives an overview of soy-maize rotation systems; (ii) examines the agronomic, economic, and nutritional benefits of utilizing soy-maize rotations; (iii) recognizes some of the limitations to widespread implementation of soy-maize rotations; and finally (iv) identifies some of the current gaps and challenges in the literature that are limiting our understanding of how to successfully implement soy-maize rotations in sub-Saharan Africa.

2. Soy and Maize in Sub-Saharan Africa

2.1. Maize. Maize is one of the most important crops worldwide and plays an integral economic and nutritional role in sub-Saharan Africa [16, 17]. Of the 197 million ha of maize farmed worldwide, 40 million ha are grown in Africa generating over 13 billion USD in gross production value in 2017 [18]. Currently, the largest producers of maize in SSA are Nigeria, Tanzania, and South Africa—with over 25% of South Africa's agricultural hectares dedicated to maize cultivation (Figure 1). Maize production is pervasive throughout central, eastern, and southern Africa, accounting for 19–35% of total agricultural hectares cultivated (Figure 2). It is also a critical source of calories throughout SSA. In both eastern and southern Africa, over 25% of daily caloric intake is provided by maize [1, 17]. However, in some areas such as Lesotho, Zambia, and Malawi, maize accounts for over 50% of daily caloric intake [17]. Demand for maize in SSA is expected to triple by 2050, suggesting that maize will continue to play a vital role well into the future [20].

Maize does well in subhumid zones and can be very sensitive to drought stress. Most varieties require between 500 and 1500 mm of rain per growing season for proper development, although there are some varieties that can survive with just over 250 mm in a growing season [21]. Maize production is most suited to deep, fertile soils with good water-holding capacity and high soil organic matter [21]. While maize originates in the tropics, growth is severely reduced at temperatures above 35°C [21]. However, it is not always possible to meet these growing requirements, and as a result, crop yields suffer. Poor soil quality and insufficient water availability are two of the largest factors limiting crop growth in SSA [11]. Finally, this problem of poor growing conditions is exacerbated by a growing trend in which maize, and other crops, is being cultivated in marginal lands that are less suitable for agriculture [21].

Maize is an important staple crop and is widely cultivated throughout SSA [16, 20]. The combination of legume (i.e., soybean) and cereal crops (i.e., maize) creates a stable system that can help protect soil fertility and reduce abiotic and biotic pressures, while also producing high yields [9, 22–24]. Indeed, yields in maize are higher when subsequently planted after soybean when compared to continuous cereal cultivation [9, 22–24]. And, unlike in continuous maize cultivation where yields decline with time, yields of soybean and maize grown in rotation can be sustained over years [22]. Consistent productivity and higher yields can help improve food security and economic livelihoods of smallholder farmers [25]. Additionally, soy-maize rotations have been very successful in other tropical parts of the world, offering great promise to intensify agricultural production in SSA [26–29].

2.2. Soybean. Soybeans were introduced to SSA in the 19th century by the Chinese, only in the last 40 years as there been commercial interest in the crop [30]. However, despite its short history on the African continent, soybean has much commercial potential due to its wide range of uses as food, livestock feed, and industrial raw material [11]. Agro-ecological analysis too shows great potential for expansion throughout sub-Saharan agriculture [31, 32]. Soybean cultivation in SSA has increased since the 1970s with over 1.5 million ha planted in 2016 (Figure 3) [30]. However, soybean cultivation in SSA still only accounts for 0.7% of total production worldwide [18]. Nonetheless, soybean production is poised to continue to grow dramatically during the 21st century, with modeling projecting wider adoption of the crop throughout the African subcontinent [11]. Presently, South Africa and Nigeria dominate soybean production in SSA, accounting for 70% of total African production in 2014 [11, 33]. Increased market and consumer demand for vegetable oils, nontraditional legumes, and animal products will continue to drive soybean expansion in the region [1, 11]. Current soybean production in SSA is unable to keep pace with present demand making SSA largely a net-importer of soy products and food oil [1, 34].

Soybean in SSA also suffers from large yield gaps and low productivity [30, 35, 36]. Globally, average soybean yields near 2.5 metric tons per hectare [37], while the small producers that dominate soybean production in sub-Saharan agriculture achieve yields of around 0.8 metric tons, or one-third the yield [38, 39]. Therefore, adding a soy rotation to maize cultivation may boost productivity, and closing the yield gap for soybean in SSA appears to be a necessary

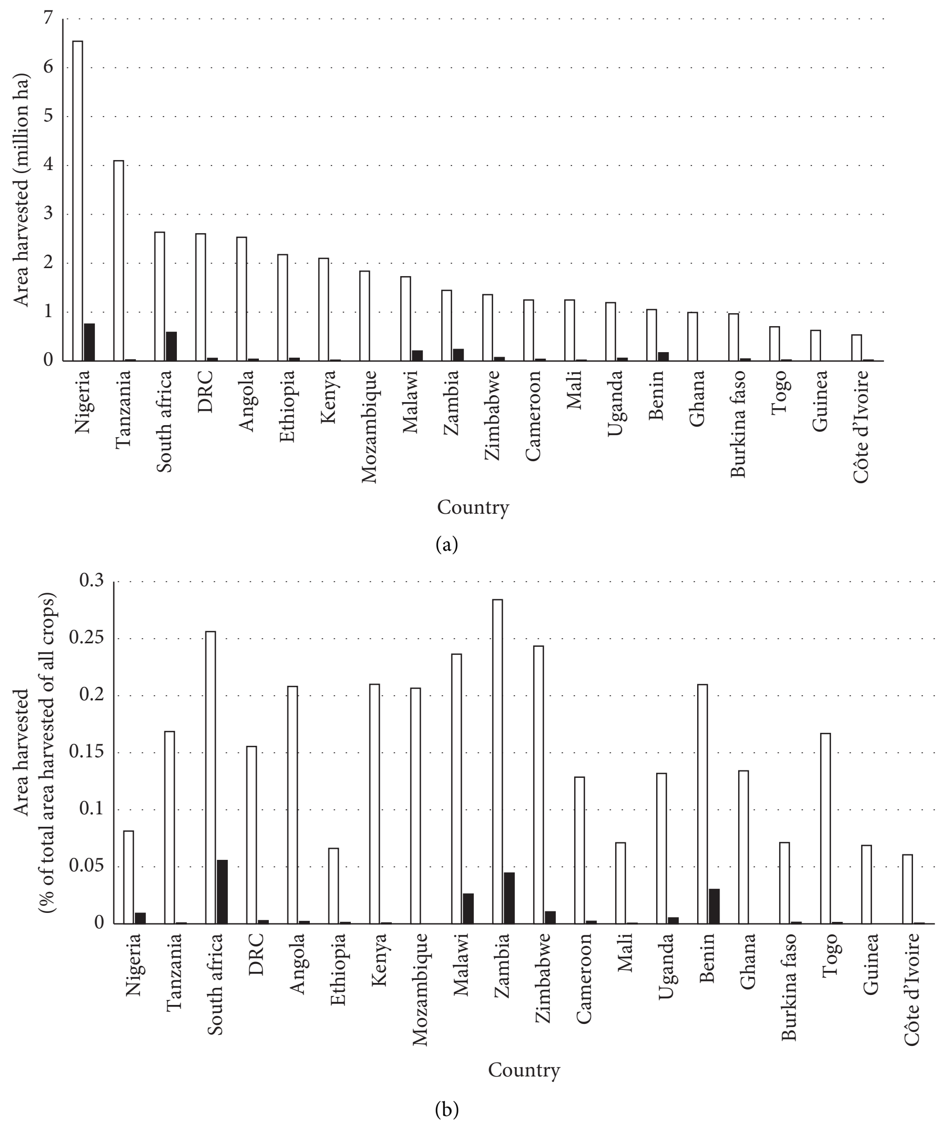

Figure 1: Countries are ordered from the greatest producer of maize to smaller producers of maize. For clarity, only the top 20 producers of maize were selected to be represented in this figure. (a) Area harvested in millions of tonnes for maize (○) and soy (●) by country. (b) Maize (○) and soy (●) as a percentage (%) of the total area harvested for all crops within a given country. Data are from FAO [19].

condition for the adoption. This yield gap can be addressed by planting varieties that are better suited to regional climates in SSA [40]. For example, maturity group VII varieties are most appropriate for eastern Africa, while VIII is better suited for western Africa [41]. Soybean typically requires between 500 and 900 mm of water per growing season. However, soybean varieties with lower transpiration rates have great potential for implementation in water-limited areas and could be valuable in marginal areas with water deficits [11, 41, 42].

2.3. A Practical Overview of Soy-Maize Rotation in Sub-Saharan Africa. Many regions of SSA plant continuous maize during both the short and long rainy seasons. However, this has many negative effects and can result in reduced soil fertility, increased pest and pathogen pressure, and a severe reduction in dietary diversity [9, 22–24, 43].

The stages of soy-maize crop rotation can be divided into different time scales based on regional climate and rainfall patterns. For example, in regions that are limited by rain, soy can be planted in one year and maize in the following. In areas that have multiple rainy seasons, such as parts of eastern and southern Africa, soy and maize can be alternated between seasons [21]. It is important to note that soy and maize have different growing requirements and require distinct cultivation practices (Table 1). The underground soybean residue must remain in the soil to achieve the full nitrogen and organic matter benefits of a soy-maize rotation [24, 44, 45]. For example, common practice involves farmers pulling the entire soybean plant, rather than cutting the plant, prior to threshing, which removes important nutrients [46].

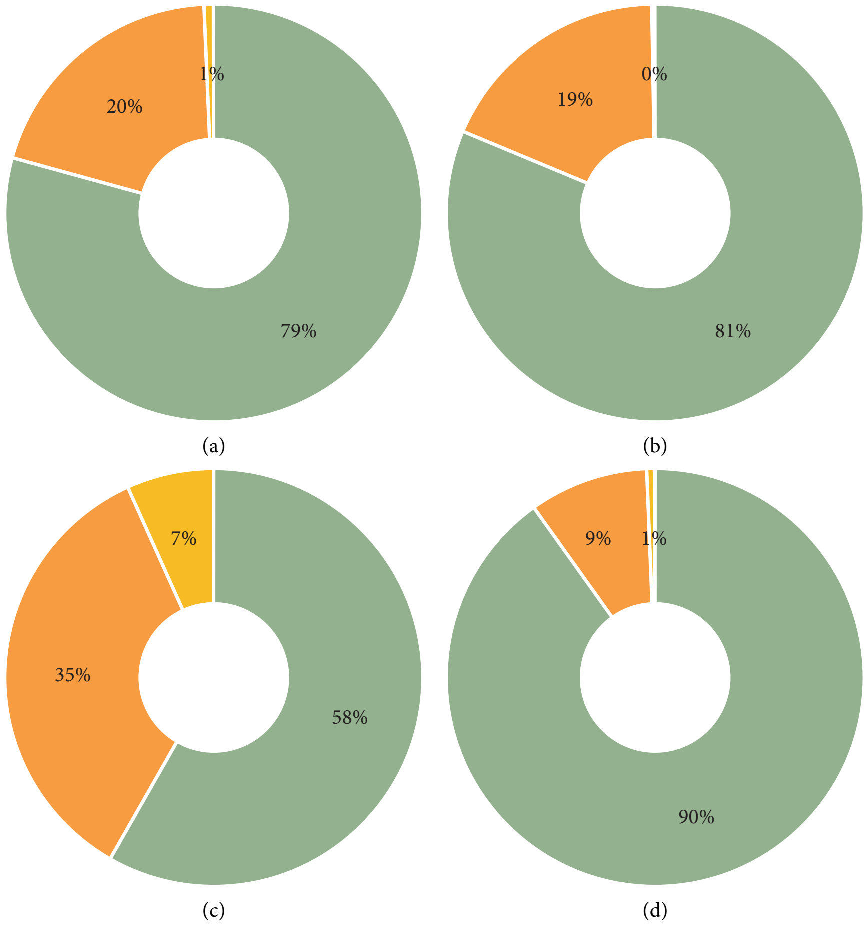

Figure 2: Maize (●) and soybean (●) as a percentage of total hectare harvested by the region of sub-Saharan Africa. Maize and soy are compared with all other crops that were produced and harvested within each region of Africa (●). (a) Eastern Africa. (b) Central Africa. (c) Southern Africa. (d) Western Africa. Data are from FAO [19].

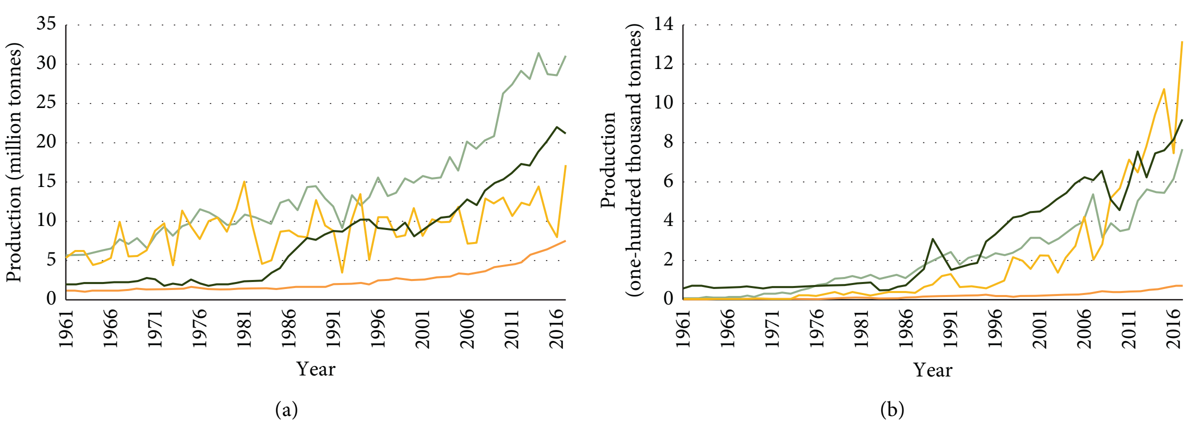

Figure 3: Production of (a) maize and (b) soy over time by the region of sub-Saharan Africa. Each color represents a different region of sub-Saharan Africa. ● Eastern Africa. ● Central Africa. ● Southern Africa. ● Western Africa. Production is represented in maize by million tonnes, while production is shown in one-hundred thousand tonnes in soybean. Data are from FAO [19].

The soy-maize rotation begins with planting soybeans. Prior to sowing soybean, it is important to fertilize the land, if possible, with single superphosphate (SSP) fertilizer. Phosphorus is especially important to soy cultivation as inadequate phosphorus fertilization can result in yield reductions of 50% [38, 44, 45, 47–49]. The suggested rate of SSP for tropical/subtropical soy production is at least 40–60 kg·P·ha^{-1} [50, 51]. Soybean in the rotation reduces the

Table 1: Summary of agronomic requirements for the cultivation of maize and soy.

Agronomic requirement	Maize	Soy
Rain requirement	500–1500 mm/growing season (some varieties can survive with ~250 mm/growing season)	500–900 mm/growing season
Fertilizer application	Nitrogen-phosphorus-potassium (NPK) 15-15-15	Single superphosphate (4–60 $kg{\cdot}P{\cdot}ha^{-1}$)
Seed inoculation	No	Yes
Construction of ridges	No	Yes
Space between rows/ ridges	75 cm	50 cm
Planting depth	5 cm	1-2 cm
Space between plants within a row	25 cm	5 cm
Growing season	~100–120 days	~100–150 days
Major pests/pathogens	Fall armyworm, stem borers, maize lethal necrosis, and maize streak geminivirus	Parasitic nematodes, bacterial pustule, frogeye leaf spot, red leaf blotch, and soybean rust

Maize and soy have different requirements for growing, including the amount of rain needed during a growing season, fertilizer requirements, row spacing, planting depth, and major pests and pathogens. Most notable are the differences in fertilization requirements between the two crops.

need for annual applications of phosphorus to the cereal, and biannual applications maximized economic returns to farmers [52]. It is highly recommended that farmers measure levels of fertility prior to cultivation through a soil test. However, limited capital and access to soil testing services makes this step difficult for many smallholder farmers [53].

After the application of SSP, ridges are made in the field 50–75 cm apart by hand, animal traction, or tractor [24, 44, 54]. Sowing can begin following a plentiful rain when soil is moist. Care should be taken to not plant soybean seeds in dry soil as it will reduce germination rates and seed emergence. Seeds are planted in a shallow groove (1-2 cm deep) along the top of the ridges, leaving 5 cm of space between each seed, 75 cm between rows for a planting population of 300,000 seeds ha^{-1} [48]. Interestingly, while the literature is clear about planting soybean densely to assure maximum yield and a canopy for weed suppression (see Ajokporise et al. 2016; [39]), a number of maize-soybean rotation studies either omit plant population as a variable or underplant their soybean (see [22, 56, 59]). Afterwards, seeds are lightly covered with loose soil, taking precaution not to pack soil on top of seed too tightly. If possible, inoculant should be added to the soybean seeds prior to sowing to improve performance and fixation of nitrogen ([30, 36]; Awuni et al. 2020).

Depending on the variety, soybeans take between 100 and 150 days to reach maturity [59]. Universally, the maize-soybean research literature does not include ancillary analyses about the role of soybean genetics supporting maize yield or nitrogen fixation. That is, differences among alternative soybean varieties with respect to maturity group, yield, disease resistance, shatter, and so on do not factor into the current research evaluating the complementarity of soybean and maize in a rotation system. Soybeans are vulnerable, and differences exist across varieties, to a number of pests and diseases such as parasitic nematodes, bacterial pustule, frogeye leaf spot, red leaf blotch, and soybean rust [60–62].

Finally, soybean plants are ready to harvest once they senesce and turn brown after grain fill [46]. Farmers should consider growing a different soybean variety better suited to their environment if the soybean plant does not grow taller than knee height at maturity [45]. Producers then sell the harvested soy for processing and final use as commercial livestock feed and food oil. Additionally, highly nutritious soy milk, flour, or tofu for human consumption are additional products derived from soy [1].

Afterwards, maize follows in the same field during the next growing season. Soybean seed requires good storage to ensure high germination rates [63]. Improper storage in tropical settings, which is particularly detrimental to soybean seed viability, serves as one of the factors keeping yields low in sub-Saharan Africa. Seed procurement from certified seed dealers is more costly and rare than the common practice of saving soybean seeds. No work to date explores the tradeoff in terms of the costs from reduced germination and yield potential, even though the saved seed is free and presents no cash or debt burden to the farmer.

Another challenge to the adoption of maize-soybean rotations involves the need to breakdown ridges built for soybean in the previous season to accommodate maize's different plant density [44]. Maize seed is sown into moist soil at a depth of 5 cm with 25 cm between plants in the same row [44]. Rows are typically spaced 75 cm apart [21]. Rows of soybean, on the other hand, are spaced rows 75 cm apart, and seed spacing is 5 cm [9].

3. The Agronomic Benefits of Soy-Maize Rotations in Sub-Saharan Africa

3.1. Utilizing Soy-Maize Rotations to Increase Soil Fertility. Several agronomic benefits are associated with the use of soy-maize rotations in the tropics, including increased soil fertility, decreased biotic pressure, and increased maize and soy yields [22–24]. Soy-maize rotations increase SSA cereal yields by an average of 0.49 tons/hectare or more in fields planted after a legume when compared to cereals in continuous cultivation [21, 23, 64]. Additionally, soy-maize rotations can maintain high levels of agricultural productivity after many years of cultivation, making this system very valuable and sustainable over time in comparison with continuous cereal production [22, 24].

Numerous studies indicate that a soy rotation is more effective at increasing yields than intercropping systems [23]. Traditionally, SSA farmers cultivate maize continuously or as part of an intercropping system with other crops, such as pulses [65]. Intercropping systems incorporate multiple crops in the same plot of land during the same season. While intercropping can be helpful in diversifying household diets, competition between crops can be problematic and affect yields under some conditions [65]. In crop rotation, a different monocrop is sequentially planted each growing season. For example, in the "safrinha" system in the central west of Brazil maize follows soybean within the same year, where the rainy season can last six months [66].

Soy rotations are widely considered a sustainable method for nutrient management in agricultural systems due to the crop's ability to fix atmospheric nitrogen into the soil [23, 24, 30]. Aboveground soybean residues are rich in nitrogen and can act as feed for livestock or be additive to next year's crop [67, 68]. This, in turn, fuels a cycle in which high-quality residues create high-quality manure that can then be added to the soil to continue to improve its fertility [69]. Leaving underground soybean residues in the soil after harvest also contributes to soil nitrogen content and organic matter [70].

Rotations that include soybean decrease the need for chemical fertilizer inputs by fixing between 17 and 450 $kg{\cdot}ha^{-1}$/year of nitrogen in tropical settings [71] and then subsequently making available between 0 and 170 $kg{\cdot}ha^{-1}$ available nitrogen for the following maize crop (Table 2). This is of great benefit to smallholder farmers, many of whom cannot afford fertilizers [30]. This increase in soil nitrogen from soy rotations can lead to increased maize yields that can be sustained over long periods of time [22]. Additionally, soybean rotations can improve cereal crop's access to both phosphorus in the soil and phosphate rock fertilizer under phosphorus-deficient conditions due to its root exudates [23, 47, 72–74].

3.2. Reducing Biotic Pressure by Implementing Soy-Maize Rotations. Crop rotations have long been accepted as a method to reduce pressure from pests and disease by disrupting disease cycles and preventing pest populations to build over time [64, 75]. The utilization of soy-maize rotations presents the opportunity for farmers to diversify their agricultural production systems and build resilience against devastating biotic factors.

Striga (*Striga hermonthica*) is one of the largest threats to maize production in SSA and can cause yield losses of up to 80% costing upwards of 7 billion USD [76–78]. However, soybean can significantly reduce the prevalence of the parasitic weed by inducing suicidal germination through the exudation of strigolactones by their roots, the weed dying shortly afterwards since soybean does not act as a host [15, 79–81]. Suicidal germination of Striga by soybean can drastically decrease Striga seedbanks in the soil, consequently reducing weed pressure in subsequent maize rotations and increasing yields by up to 90% [23, 80]. Planting soybean is preferable to leaving fields fallow as many native grasses can act as a host to Striga and increase the weed's seedbank in the soil [23].

The ability to reduce pest pressure with soy-maize rotations is less clear with nematodes, stem borers, and fall armyworm. Some limited research exists on the effects of soybean to reduce such pest pressure on maize. Soybeans, for example, are not effective at controlling nematode populations since they can act as a host and cause buildups of nematode populations in the field [82]. However, while nematodes can be devastating to cereal crops, damage to maize from nematodes does not reach economic thresholds in SSA. Soy-maize rotations can increase attacks by stem borers in the field likely due to the increased nutritional status of maize from planting after soybean [23, 83]. However, with both nematodes and stem borers, the benefits conferred by including a soy rotation outweigh the damage caused by pests due to increased maize productivity [23].

Lastly, fall armyworm can be devastating to maize yields in SSA, creating yield losses of 20–50% and costing up to \$6.2 billion USD annually [19, 84]. As of 2018, only 10 countries on the African continent have not become infested with fall armyworm [19]. Although fall armyworm can affect soybean, it typically acts as a secondary pest, preferring C_4 grasses [85, 86]. Yet, soybean can become completely defoliated by fall armyworms in circumstances where severe infestations of a typical host, such as maize, precede the planting of soy [86]. At the moment, little information is available, so more research needs to be carried out about the effects on fall armyworm when including soy in a rotation system with maize.

4. The Nutritional and Economic Benefits of Soy-Maize Rotations

Overwhelmingly, cereal consumption dominates diets in SSA. The lack of dietary diversity can lead to nutritional deficiencies [1]. On average, cereals made up 20% of the household food basket in 2010 in western African urban areas [1]. This percentage is even higher in rural areas, where 34% of the household food basket is made up of cereals [1]. Additionally, the proportion of calories provided by maize in SSA will increase by the year 2025 [1]. While rates of hunger in SSA have decreased markedly since the 1990s, rates of malnutrition remain stubbornly high with the average rate of child stunting and wasting at 33% and 7.4%, respectively [1, 4, 5]. As a result, there has been a great shift in ensuring that people worldwide not only have food security in the form of enough calories but also access to enough nutrients to prevent conditions resulting from malnutrition [1].

Continuous maize cultivation crowds out potential nutritionally complementary crops and thus can be a causal force limiting dietary diversity throughout SSA [87]. Correspondingly, many studies and policy recommendations have called for increased diet diversification, beginning with more varied agricultural production [87]. The objective being that improved nutrition reduces the likelihood of stunting as well as increasing resilience to illness and disease in turn preserves

Table 2: Maize: soybean rotation studies: key variables and nitrogen carryover levels.

Year	Lead author	Variable of interest	Country	N carryover
1989	Parkinson	Disease	Nigeria	NA**
1989	MacColl	Nitrogen	Malawi	0–28 kg·ha^{-1}
1999	Kasasa	Yield* nitrogen	Zimbabwe	9–170 kg·ha^{-1}
2000	Sauerbon	Yield*	Ghana	NA**
2006	Agyare	Yield*	Ghana	NA**
2006	Jemo	Nitrogen	Cameroon	17–45 kg·ha^{-1}
2006	Ojiem	Socio-economics	Kenya	NA**
2007	Zingore	Yield* socio-economics	Zimbabwe	0–62 kg·ha^{-1}
2008	Franke	Yield* nitrogen	Nigeria	3–50 kg·ha^{-1}
2009	Kihara	Yield* socio-economics	Kenya	52–90 kg·ha^{-1}
2010	Anyanzwa	Yield*	Kenya	NA**
2010	Oikeh	Yield*** nitrogen	Benin	21 kg·ha^{-1}
2013	Bado	Yield* nitrogen	Burkina Faso	30–42 kg·ha^{-1}
2016	Nyagumbo	Yield*	Malawi, Mozambique	NA**
2018	Franke	Yield*		NA**
2019	Uzoh	Yield*	Nigeria	16–46 kg·ha^{-1}

*Maize yield improvement. **Not applicable. ***Rice yield improvement.

human capital [4, 88]. Reducing the population affected by preventable conditions with lifelong consequences, increases the number of people that can contribute economically and achieve greater social mobility [89, 90].

Soybean cultivation presents an opportunity to provide a good source of proteins, vitamins, and minerals to complement currently carbohydrate-heavy diets and provide essential amino acids not found in maize [1]. However, the adoption of soybean into African diets is a major obstacle. Currently, Africa accounts for only ~5% (618,000 tons) of global soybean consumption [59]. Nevertheless, there are several initiatives teaching farming families in SSA on how to process harvested soybean into nutritious milk, flours, and curds to be eaten by the household [59]. Similarly, recent research in northern Ghana showed locally available soy flour to be twice as economical as other locally available proteins (beef and dried mackerel) for the protein fortification of national school lunches [91].

Numerous studies have found that increased agricultural productivity reduces poverty and increased incomes [92–94]. This is especially true in rural areas, where most people depend on upon agriculture for their livelihoods and employment [25]. Soy-maize rotations, in theory, support higher incomes through greater maize productivity complemented with a soy high-demand cash crop [95] that also has numerous uses at the household level (Figure 4) [1]. Soybean, too introduces high job and value-added multipliers that help economic development across a number of industrial sectors, such as upstream inputs and mechanization and downstream feed and livestock and food processing, oil, and manufacturing [1, 34, 96]. For example, the increase in soybean production has led to an expansion in soybean crushing and processing facilities. From 1986 to 2016, crushing increased from 25,000 tons to 1 million tons in South Africa and from 5,000 tons to 350,000 tons in Nigeria [30]. Currently, some crushing and processing plants in SSA are only working at 30% of their operational capacity, indicating opportunities for greater production and employment in the future as more soy is regionally produced [11].

5. Challenges to Implementation

5.1. Regional Differences. To effectively implement soy-maize rotations, it is important to acknowledge the tremendous amount of diversity present economically, politically, culturally, and ecologically in SSA [97]. Soil types, rainfall, and climate patterns all vary greatly both within countries and across the entire continent affecting how soy-maize rotation can be applied. Sometimes these factors can act as an inhibitor or limitation to the adoption of new agricultural techniques and technologies [1]. Consequently, there is no singular way to increase agricultural intensification through soy-maize rotations, and approaches need to be tailored to the needs of specific regions. Additionally, many of the challenges that affect soy-maize rotation efficacy are the same issues that generally affect agricultural production in SSA such as poor infrastructure, inadequate farmer extension services, limited access to agricultural resources and inputs, limited access to markets, climate change, and political instability or civil strife [1, 10, 14].

Some regions of SSA may not be well-suited for soybean cultivation with current varieties. Insufficient early season rainfall has the potential to limit the expansion of current soybean varieties grown in SSA [11]. For example, farmers in Malawi have access to only one variety, Tikalore released in 2011, even though the country contains varied agro-ecological zones and photoperiod variation that stretches from 9 to 16 degrees south latitude. In areas that are very prone to drought stress, such as the Sudano-Sahelian region, it may be more effective to grow hardier legumes such as cowpea or groundnut [23]. However, there are opportunities to grow soybean in these regions with adequate development of drought-tolerant/shorter-season varieties [11].

5.2. Environmental Sustainability. In general, climate change poses significant risks to farmers depending on rain-fed cropping systems. A maize-soybean rotation fits within the class of policy tools to address soil improvement and cropping

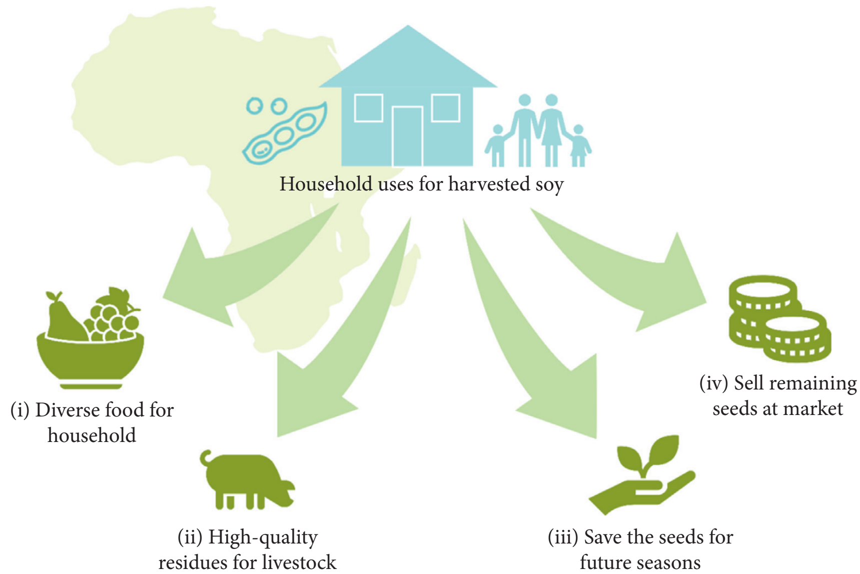

Figure 4: The outcomes for harvested soy at the household level. Soybean that is harvested can be used as (i) a direct food source for the household, increasing dietary diversity; (ii) a high-quality residue for livestock, improving animal nutrition and manure quality; (iii) seed for future seasons; (iv) a source of additional income when remaining soybean crop is sold at market. These outcomes help to improve the agronomic performance of the household's agricultural operation, while also improving the nutritional status and economic livelihood of households in sub-Saharan Africa.

flexibility, and by doing so, it indirectly improves farmer resiliency to drought conditions brought on by climate change. However, no work to date explicitly addresses the environmental sustainability of a maize-soybean rotation.

There has been significant research on how maize and soybean production will fair in the tropics under various climate change scenarios. In general, countries in SSA are particularly vulnerable to climate change due to their dependence on rain-fed agriculture [98]. It is generally accepted that climate change will, overall, result in reductions to maize yields across SSA [99–101]. However, projections have been less conclusive about soy. While many studies examine the effects of climate change on soy production in SSA, a consensus on what to expect in the future has not been reached [11, 102]. Researchers need to better understand likely outcomes of soybean in general from climate change and then synergies for both crops when rotating with maize. Much research and development has taken place to develop short season and early soybean varieties in the Brazilian tropics to allow for greater managerial flexibility under varying moisture conditions, not specific to climate change, within a double cropping system [66].

5.3. Market Access. Access to markets is critically important to the adoption of soy-maize rotations. Some parts of SSA, such as South Africa and Nigeria, have well-established markets for soybean. However, in rural areas where infrastructure is poor, access to markets to sell soybean can be limited, and it can be difficult to link producers to buyers [11]. These barriers discourage farmers and inhibit the adoption of soybean production and new soybean technologies [11]. For example, the lack of market connections between soy producers and buyers resulted in the near-complete abandonment of soy production in Tanzania [62]. Furthermore, inconsistent regional producer price data make it difficult to accurately predict profits from soybean rotation, also potentially discouraging soybean production [11]. Martey et al. [95] show alternatively that prices, at least in Ghana, are efficient, integrated with international prices, and fair. Thus, low profitability results from other factors such as low yield, insufficient storage, and low production volumes, not low prices.

5.4. Access and Use of Inputs. Another major challenge to the adoption of soy-maize adoption is the initial lack of access to agricultural inputs, such as high-quality seeds, fertilizers, and pesticides, and extension services. Extension services are vital to the success of farmers worldwide [103]. However, limited infrastructure and ability for farmers to connect with extension services may perpetuate lower crop productivity into the future. Accessing agricultural resources has been a persistent problem for smallholder farmers in SSA [10, 104]. While soy-maize rotations should reduce the need for some inputs, such as fertilizer, pesticides, and herbicides, and raise income through the production of higher yields, there may still be issues with farmers accessing agricultural services that could improve productivity.

To date, no research exists on the interplay of gender and adoption of maize-soybean rotation systems. In general, women lag behind men in the area of new technology adoption, access to agriculture inputs for crop production, and opportunities to engage information services through private or public extension systems [105, 106]. The adoption of a maize-soybean rotation changes tillage, planting, and harvesting practices, thus challenging the current labor structure where women provide most of the labor [107].

Figure 5: SIL's multicrop thresher that processes maize and soybean as well as other crops [109].

Research field	Type of research*	Current state of research**
		Limited / Moderate / Good
Agronomy	S	Good
Production	I	Limited
Soils	S	Moderate
Economics	I	Limited
Disease	I	Limited
Pests	I	Limited
Weeds	S	Moderate
Gender	I	Limited
Sustainability and climate change	I	Limited
Nutrition	S	Good
Mechanization	I	Limited
Labor management	I	Limited

Note. *S = maize-soybean system research; maize only or soybean only independently researched
Note. **Red = limited; blue = moderate; green = good

Figure 6: Summary of the current state of the literature on maize-soybean rotation system research.

For example, women provide almost all of the labor for hand threshing soybean, a laborious process than takes about 40 hours per acre of soybean [108]. The maize-soybean rotation literature does not address the labor or mechanization implications when adopting the system. USAID's Soybean Innovation Lab recently introduced a locally made multicrop mechanical thresher that can handle both maize and soybean (as well as rice, sorghum, millet, and cowpea) to specifically address the augmented labor demands. Mechanization shifts women's roles from the laborious and time consuming task of threshing to supervising the threshing of their soybean crop (Figure 5). Such a thresher that handles both maize and soybean may not only make soybean harvesting easier and more efficient but also support the adoption of a rotation system. As noted above, rotation systems are more complex and disruptive than traditional monocropping systems, especially when adding a commercial crop. Therefore, labor, gender, mechanization, and input adoption not only become constraints for adoption but also are the key areas requiring research.

6. Conclusions

In sum, limited work has been carried out on maize-soybean rotations for SSA (Figure 6), especially when considering maize-soybean rotation practices as a physical, biological, social, and economic system. Addressing this gap between an agronomic or component approach versus a systems understanding of the maize, soybean rotation may provide the knowledge necessary to sufficiently increase yields and profitability and, by doing so, may close the adoption gap

Africa faces compared with the rest of the world. For example, no work explicitly looks at maize-soybean rotations to improve resiliency in the tropics to the effects of climate change. The openings for further research are especially apparent in light of the success of the soybean-maize succession system that dominates row crop agriculture in tropical Brazil. However, this system involves large producers operating in a 180-day rainy season. The small holders of Africa would benefit from maize-soybean rotation research which adapted to their production, infrastructure, institutions, and socioeconomic realities.

This research clearly shows that soy-maize rotations have the potential to increase resilience to biotic and abiotic factors, which historically have contributed to the risk environment that small holders face. There has been some work, especially on Striga, but researchers have not tackled other big challenges for small holders such as other invasive weeds, fungal diseases, pests such as nematodes and fall armyworm, and pesticide/herbicide application management within a systems framework.

Good work has been taken place on the nutritional complementarity of adding a tropical protein crop, such as soybean, to provide dietary diversity to the starch-based diet of much of SSA, and by doing so, it address conditions such as child stunting and wasting. However, little work has touched the socioeconomic conditions, such as labor and gender, farmers face when switching from monocropping, a household staple crop (maize), to a rotation system involving a commercial nonstaple crop like soybean.

Farmers may think of a rotation crop as a substitute for maize, which may make them food-insecure, especially when the complement is a cash crop like soy. Land availability may be limited, and planting a second crop means planting fewer hectares of maize. Though yields, cash flow, and profitability may rise adding a second crop like soy, at the margin, there would be real risk for small holders when planting less maize, which is so fundamental to the local diet. Soybean, unlike maize, is neither native to the cuisine nor the cultural practices of local farmers, so soybean involves a number of major adaptations where the outcome is uncertain. As a result, small holders can achieve low yields when they first start to plant soybean, which makes adopting a rotation system difficult. Researchers need to provide guidance on how best it is for small holders to reduce the risk and uncertainty associated with a new commercial crop like soybean.

Specifically, to realize the full potential of soy-maize rotations, future research efforts should concentrate on (i) further understanding of the effect of pests and pathogens on soy-maize rotations, outside of Striga, especially fall armyworm; (ii) realizing a consensus on the effect of climate change on the production and yields of soybean in SSA; (iii) developing climate-smart soybean varieties that can cope with water limitations, early planting dates, 90-day (short) growing season, and the high elevations of eastern Africa; (iv) and linking farmers with adequate agricultural resources and private and/or public extension services to better handle the novelties of producing a commercial tropical legume; and (v) addressing the socioeconomic realities for small holders where soybean yield and profitability are low and labor demands are high [110].

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The Feed the Future Innovation Lab for Soybean Value Chain Research (Soybean Innovation Lab (SIL)) under the U.S. Government's global hunger and food security initiative, Feed the Future, funded this research. The USAID award number is AID-OAA-L-14-00001.

References

[1] OECD/FAO, "Chapter 2—agriculture in Sub-Saharan Africa: prospects and challenges for the next decade," *OECD-FAO Agricultural Outlook 2016–2025*, OECD Publishing, Paris, France, Special Focus: Sub-Saharan Africa, 2016.

[2] M. Andersson, A. Saltzman, P. S. Virk, and W. H. Pfeiffer, "Progress update: crop development of biofortified staple food crops under HarvestPlus," *African Journal of Food, Agriculture, Nutrition and Development*, vol. 17, no. 2, pp. 11905–11935, 2017.

[3] L. R. Buisman, E. Van de Poel, O. O'Donnell, and E. K. A. van Doorslaer, "What explains the fall in child stunting in Sub-Saharan Africa?" *SSM—Population Health*, vol. 8, Article ID 100384, 2019.

[4] E. Skoufias, *All Hands on Deck: Halting the Vicious Circle of Stunting in Sub-Saharan Africa*, World Bank, Washington, DC, USA, 2018, https://blogs.worldbank.org/health/all-hands-deck-halting-vicious-circle-stunting-sub-saharan-africa.

[5] UNICEF, *Levels and Trends in Child Malnutrition: Key Findings of the 2017 Edition*, UNICEF/WHO/ World Bank Group, New York, NY, USA, 2017, https://www.who.int/nutgrowthdb/jme_brochoure2017.pdf.

[6] M. K. Van Ittersum, L. G. J. Van Bussel, J. Wolf et al., "Sub-Saharan Africa feed itself?" *Proceedings of the National Academy of Sciences*, vol. 113, no. 52, pp. 14964–14969, 2016.

[7] J. Dixon, A. Gulliver, and D. Gibbon, *Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World*, FAO and World Bank, Rome, Italy and Washington, DC, USA, 2001.

[8] D. Harris and A. Orr, "Is rainfed agriculture really a pathway from poverty?" *Agricultural Systems*, vol. 123, pp. 84–96, 2014.

[9] I. Nyagumbo, S. Mkuhlani, C. Pisa, D. Kamalongo, D. Dias, and M. Mekuria, "Maize yield effects of conservation agriculture based maize-legume cropping systems in contrasting agro-ecologies of Malawi and Mozambique," *Nutrient Cycling in Agroecosystems*, vol. 105, no. 3, pp. 275–290, 2016.

[10] Z. Tadele, "Raising crop productivity in Africa through intensification," *Agronomy*, vol. 7, no. 1, p. 22, 2018.

[11] C. H. Foyer, K. H. M. Siddique, A. P. K. Tai et al., "Modelling predicts that soybean is poised to dominate crop production across Africa," *Plant, Cell & Environment*, vol. 42, no. 1, pp. 373–385, 2018.

[12] S. Kelley, *Depleted Soil Locks Rural Farmers in Trap of Ultra-Poverty*, Cornell Chronicle-Cornell University, Ithaca, NY,

USA, 2015, https://news.cornell.edu/stories/2015/11/depleted-soil-locks-rural-farmers-trap-ultra-poverty.

[13] R. J. Hillocks, “Addressing the yield gap in Sub-Saharan Africa,” *Outlook on Agriculture*, vol. 43, no. 2, pp. 85–90, 2014.

[14] F. F. K. Byamugisha, *Securing Africa’s Land for Shared Prosperity: A Program to Scale up Reforms and Investments*, International Bank for Reconstruction and Development, The World Bank, Washington, DC, USA, 2013.

[15] V. Parkinson, S. K. Kim, Y. Efron, L. Bello, and K. Dashiell, “Striga, improved management in Africa,” in *Proceedings of the FAO/OAU All-Africa Government Consultation on Striga Control*, vol. 96, p. 136In Striga Control for Africa, Maroua, Cameroon, October 1989.

[16] B. Badu-Apraku and M. A. B. Fakorede, “Maize in Sub-Saharan Africa: importance and production constraints,” *Advances in Genetic Enhancement of Early and Extra-early Maize for Sub-Saharan Africa*, Springer International Publishing, Cham, Switzerland, 2017.

[17] A. Harashima, “Maize and Grace: Africa’s encounter with a new world crop, 1500–2000-by James C. McCann,” *The Developing Economies*, vol. 45, no. 2, pp. 242–245, 2007.

[18] FAOStat, *Crop Production Data [Maize]*, FAOStat, Rome, Italy, 2019, http://www.fao.org/faostat/en/#data/QC.

[19] FAO, *Fall Armyworm keeps Spreading and becomes more Destructive*, Food and Agriculture Organization, Rome, Italy, 2018, http://www.fao.org/news/story/en/item/1142085/icode/.

[20] O. Ekpa, N. Palacios-Rojas, G. Kruseman, V. Fogliano, and A. R. Linnemann, “Sub-Saharan African maize-based foods: technological perspectives to increase the food and nutrition security impacts of maize breeding programmes,” *Global Food Security*, vol. 17, pp. 48–56, 2018.

[21] F. Baijukya, L. Wairegi, K. Giller, S. Zingore, R. Chikowo, and P. Mapfumo, *Maize-Legume Cropping Guide*, Africa Soil Health Consortium, Nairobi, Kenya, 2016.

[22] W. A. Agyare, V. A. Clottey, H. Mercer-Quashire, and J. M. Kombiok, “Maize yield response in a long-term rotation and intercropping systems in the Guinea Savannah Zone of Northern Ghana,” *Journal of Agronomy*, vol. 5, no. 2, pp. 232–238, 2006.

[23] A. C. Franke, G. J. van den Brand, B. Vanlauwe, and K. E. Giller, “Sustainable intensification through rotations with grain legumes in Sub-Saharan Africa: a review,” *Agriculture, Ecosystems & Environment*, vol. 261, pp. 172–185, 2018.

[24] I. M. Uzoh, C. A. Igwe, C. B. Okebalama, and O. O. Babalola, “Legume-maize rotation effect on maize productivity and soil fertility parameters under selected agronomic practices in a sandy loam soil,” *Scientific Reports*, vol. 9, Article ID 8539, 2019.

[25] FAO, “Chapter 4—food supply systems in Africa,” *Agriculture Food and Nutrition for Africa—A Resource Book for Teachers of Agriculture*, Publishing Management Group, FAO Information Division, Rome, Italy, 1997.

[26] M. M. Adie and A. Krisnawati, “Identification of soybean genotypes adaptive to tropical area and suitable for industry,” *Earth and Environmental Science*, vol. 102, Article ID 012045, 2018.

[27] A. P. Duarte and C. Kappes, “Evolução dos sistemas de cultivo de milho no Brasil,” *Informações Agronômicas*, vol. 152, pp. 15–18, 2015.

[28] P. Goldsmith and K. Montesdeoca, “The productivity of tropical grain production,” *International Journal of Agricultural Management*, vol. 6, pp. 90–99, 2018.

[29] J. Oliveira Duarte, J. C. Cruz, and J. C. Garcia, *Evolução da Produção da Milho Safrinha no Estado de Mato Grosso*, Embrapa Agropecuária Oeste—Comitê de Publicações da Unidade, Mato Grosso do Sul, Brazil, 9° Seminário Nacional Milho Safrinha Rumo à Estabilidade, 2007.

[30] D. M. Khojely, S. E. Ibrahim, E. Sapey, and T. Han, “History, current status, and prospects of soybean production and research in Sub-Saharan Africa,” *The Crop Journal*, vol. 6, no. 3, pp. 226–235, 2018.

[31] N. I. Gasparri, T. Kuemmerle, P. Meyfroidt, Y. Waroux, and H. Kreft, “The emerging soybean production frontier in southern Africa: conservation challenges and the role of south-south telecouplings,” *Conservation Letters*, vol. 9, no. 1, pp. 21–31, 2015.

[32] IIASA, *Suitability for Rain-Fed Soybean, Maximizing Technology Mix*, IIASA, Laxenburg, Austria, 2002, https://webarchive.iiasa.ac.at/Research/LUC/SAEZ/.

[33] M. Cornelius and P. D. Goldsmith, “Soybean yield in Africa,” *African Journal of Food Agriculture Nutrition and Development*, vol. 19, no. 5, pp. 15169–15172, 2019, Special Issue. The State of Soybean in Africa.

[34] C. Nicholson, van de Mheen, Matyoko, T. Schmit, and P. D. Goldsmith, “Assessing the economic contribution of the soybean value chain in Kenya,” Research Report, Soybean Innovation Lab, Urbana, IL, USA, 2019.

[35] A. Margenot, “Soils,” *African Journal of Food Agriculture Nutrition and Development*, vol. 19, no. 5, pp. 15109–15115, 2019, Special Issue. The State of Soybean in Africa.

[36] J. Ulzen, R. C. Abaidoo, N. Ewusi-Mensah, and C. Masso, “On-farm evaluation and determination of sources of variability of soybean response to *Bradyrhizobium* inoculation and phosphorus fertilizer in Northern Ghana,” *Agriculture, Ecosystems & Environment*, vol. 267, pp. 23–32, 2018.

[37] FAOStat, *Crop Production Data [Soybean]*, FAOStat, Rome, Italy, 2020, http://www.fao.org/faostat/en/#data/QC.

[38] N. A. Taliman, Q. Dong, K. Echigo, V. Raboy, and H. Saneoka, “Effect of phosphorus fertilization on the growth, photosynthesis, nitrogen fixation, mineral accumulation, seed yield, and seed quality of a soybean low-phytate line,” *Plants*, vol. 8, no. 5, p. 119, 2019.

[39] D. Wiebe, A. C. Franke, and K. E. Giller, “Participatory research to close the soybean yield gap on smallholder farms in Malawi,” *Experimental Agriculture*, vol. 53, no. 3, pp. 396–415, 2017.

[40] M. Santos, “Soybean varieties in Sub-Saharan Africa,” *African Journal of Food Agriculture Nutrition and Development*, vol. 19, no. 5, pp. 15136–15139, 2019, Special Issue. The State of Soybean in Africa.

[41] T. R. Sinclair, H. Marrou, A. Soltani, V. Vadez, and K. C. Chandolu, “Soybean production potential in Africa,” *Global Food Security*, vol. 3, no. 1, pp. 31–40, 2014.

[42] South African Department of Agriculture, Forestry, and Fisheries, *Soya Beans—Production Guidelines*, Department of Agriculture, Forestry, and Fisheries, Pretoria, South Africa, 2010, https://www.nda.agric.za/docs/brochures/soya-beans.pdf.

[43] A. D’Souza and D. Joliffe, “Food insecurity in vulnerable populations: coping with food price shocks in Afghanistan,” *American Journal of Agricultural Economics*, vol. 96, no. 3, pp. 790–812, 2014.

[44] FAO, *Growing Maize and Soybean in Rotation*, FAO, Rome, Italy, 2010.

[45] Soybean Innovation Lab (SIL), "How to grow soybean in Ghana," USAID Soybean Innovation Lab, Urbana, IL, USA, 2019, http://soybeaninnovationlab.illinois.edu/files/agronomy%20extensionGhana.pdf.

[46] I. Y. Dugje, L. O. Omoigui, F. Ekeleme, R. Bandyopadhyay, P. L. Kumar, and A. Y. Kamara, *Farmers' Guide to Soybean Production in Northern Nigeria*, IITA, Ibadan, Nigeria, 2009.

[47] M. Jemo, R. C. Abaidoo, C. Nolte, M. Tchienkoua, N. Sanginga, and W. J. Horst, "Phosphorus benefits from grain-legume crops to subsequent maize grown on acid soils of Southern Cameroon," *Plant and Soil*, vol. 284, no. 1-2, pp. 385–397, 2006.

[48] N. Lee, "Agronomy in African smallholder systems," *African Journal of Food Agriculture Nutrition and Development*, vol. 19, no. 5, pp. 15131–15135, 2019, Special Issue. The State of Soybean in Africa.

[49] J. Sauerborn, H. Sprich, and H. Mercer-Quarshie, "Crop rotation to improve agricultural production in Sub-Saharan Africa," *Journal of Agronomy and Crop Science*, vol. 184, no. 1, pp. 67–72, 2000.

[50] K. N. Devi, L. N. K. Singh, T. Sunanda et al., "Response of soybean [*Glycine max* (L.) Merrill] to sources and levels of phosphorus," *Journal of Agricultural Science*, vol. 4, no. 6, pp. 44–53, 2012.

[51] A. Olaniyan, E. Udo, and A. Afolami, "Performance of soybean (*Glycine max* L.) influenced by different rates and sources of phosphorus fertilizer in south-west Nigeria," *AGROFOR International Journal*, vol. 1, pp. 46–51, 2016.

[52] J. Kihara, B. Vanlauwe, B. Waswa, J. M. Kimetu, J. Chianu, and A. Bationo, "Strategic phosphorus application in legume-cereal rotations increases land productivity and profitability in Western Kenya," *Experimental Agriculture*, vol. 46, no. 1, pp. 35–52, 2010.

[53] J. N. Chianu, J. N. Chianu, and F. Mairura, "Mineral fertilizers in the farming systems of Sub-Saharan Africa. A review," *Agronomy for Sustainable Development*, vol. 32, no. 2, pp. 545–566, 2012.

[54] A. C. Franke, G. Laberge, B. D. Oyewole, and S. Schulz, "A comparison between legume technologies and fallow, and their effects on maize and soil traits, in two distinct environments of the West African Savannah," *Nutrient Cycling in Agroecosystems*, vol. 82, no. 2, pp. 117–135, 2008.

[55] D. Ajokporise, A. U. Omoregie, F. O. Ogedegbe, and M. E. Alleh, "Growth and yield of soybean (Glycine max (L.) Merr) as affected by plant population and herbicide weed control methods in delta state," *International Journal of Innovative Agriculture & Biology Research*, vol. 6, no. 1, pp. 24–34, 2018.

[56] D. MacColl, "Studies on maize (*Zea mays*) at Bunda, Malawi. II. Yield in short rotations with legumes," *Experimental Agriculture*, vol. 25, no. 3, pp. 367–374, 1989.

[57] S. Zingore, H. K. Murwira, R. J. Delve, and K. E. Giller, "Variable grain legume yields, responses to phosphorus and rotational effects on maize across soil fertility gradients on African smallholder farms," *Nutrient Cycling in Agroecosystems*, vol. 80, no. 1, pp. 1–18, 2008.

[58] G. A. Awuni, D. B. Reynolds, P. D. Goldsmith, C. A. N. Tamimie, and N. Denwar, "Agronomic and Economic Evaluation of Input Bundle of Soybean in Moderately-acidic Savannah Soils of Ghana," *Agrosystems, Geosciences & Environment*, p. 28, 2020.

[59] International Institute of Tropical Agriculture (IITA), *Soybean*, International Institute of Tropical Agriculture, Ibadan, Nigeria, 2019, https://www.iita.org/cropsnew/soybean-2/.

[60] G. L. Hartman and H. M. Murithi, "Soybean diseases: unique situations in Africa," *African Journal of Food Agriculture Nutrition and Development*, vol. 19, no. 5, pp. 15126–15130, 2019, Special Issue. The State of Soybean in Africa.

[61] R. S. Kawuki, E. Adipala, J. Lamo, and P. Tukamuhabwa, "Responding to the soybean rust epidemic in Sub-Saharan Africa. A review," *Africa Crop Science Journal*, vol. 11, no. 4, pp. 301–318, 2003.

[62] H. M. Murithi, F. Beed, P. Tukamuhabwa, B. P. H. J. Thomma, and M. H. A. J. Joosten, "Soybean production in eastern and Southern Africa and threat of yield loss due to soybean rust caused by *Phakopsora pachyrhizi*," *Plant Pathology*, vol. 65, no. 2, pp. 176–188, 2015.

[63] A. A. Kandil, A. E. Sharief, and M. S. Sheteiwy, "Effect of seed storage periods, conditions and materials on germination of some soybean seed cultivars," *American Journal of Experimental Agriculture*, vol. 3, no. 4, pp. 1020–1043, 2013.

[64] F. C. Stevenson and C. van Kessel, "A landscape-scale Assessment of the nitrogen and non-nitrogen rotation benefits of pea," *Soil Science Society of America Journal*, vol. 60, no. 6, pp. 1797–1805, 1996.

[65] M. Kermah, A. C. Franke, S. Adjei-Nsiah, B. D. K. Ahiabor, R. C. Abaidoo, and K. E. Giller, "Maize-grain legume intercropping for enhanced resource use efficiency and crop productivity in the Guinea Savanna of Northern Ghana," *Field Crops Research*, vol. 213, pp. 38–50, 2017.

[66] P. D. Goldsmith, A. G. Martins, and A. D. de Moura, "The economics of post-harvest loss: a case study of the new large soybean—maize producers in tropical Brazil," *Food Security*, vol. 7, no. 4, pp. 875–888, 2015.

[67] H. Anyanzwa, J. R. Okalebo, C. O. Othieno, A. Bationo, B. S. Waswa, and J. Kihara, "Effects of conservation tillage, crop residue and cropping systems on changes in soil organic matter and maize–legume production: a case study in Teso district," in *Innovations as Key to the Green Revolution in Africa*, pp. 205–213, Springer, Dordrecht, Netherlands, 2011.

[68] B. V. Bado, M. P. Cescas, A. Bationo, M. P. Sedogo, and T. Traore, "Influence of legumes on nitrogen (N) fertilizer recommendations for succeeding sorghum in the Guinea Savannah of West Africa," *African Journal of Agricultural Research*, vol. 8, no. 49, pp. 6416–6421, 2013.

[69] M. Kermah, A. C. Franke, S. Adjei-Nsiah, B. D. K. Ahiabor, R. C. Abaidoo, and K. E. Giller, "N2-fixation and N contribution by grain legumes under different soil fertility status and cropping systems in the Guinea Savanna of Northern Ghana," *Agriculture, Ecosystems & Environment*, vol. 261, pp. 201–210, 2018.

[70] P. Kasasa, S. Mpepereki, K. Musiyiwa, F. Makonese, and K. E. Giller, "Residual nitrogen benefits of promiscuous soybeans to maize under field conditions," *African Crop Science Journal*, vol. 7, no. 4, pp. 375–382, 1999.

[71] M. B. Peoples and E. T. Craswell, "Biological nitrogen fixation: investments, expectations and actual contributions to agriculture," *Biological Nitrogen Fixation for Sustainable Agriculture*, vol. 141, no. 1-2, pp. 13–39, 1992.

[72] M. Nuruzzaman, H. Lambers, M. D. Bolland, and E. J. Veneklaas, "Phosphorus benefits of different legume crops to subsequent wheat grown in different soils of Western Australia," *Plant and Soil*, vol. 271, no. 1-2, pp. 175–187, 2005.

[73] P. Pypers, M. Huybrighs, J. Diels, R. Abaidoo, E. Smolders, and R. Merckx, "Does the enhanced P acquisition by maize following legumes in a rotation result from improved soil P availability?" *Soil Biology and Biochemistry*, vol. 39, no. 10, pp. 2555–2566, 2007.

[74] A. E. Richardson, P. J. Hocking, R. J. Simpson, and T. S. George, "Plant mechanisms to optimise access to soil phosphorus," *Crop and Pasture Science*, vol. 60, no. 2, pp. 124–143, 2009.

[75] FAO, *How to Practice Integrated Pest Management?*, Food and Agriculture Organization, Rome, Italy, 2019, http://www.fao.org/agriculture/crops/thematic-sitemap/theme/spi/scpi-home/managing-ecosystems/integrated-pest-management/ipm-how/en/.

[76] J. G. Gethi, M. E. Smith, S. E. Mitchell, and S. Kresovich, "Genetic diversity of *Striga hermonthica* and *Striga asiatica* populations in Kenya," *Weed Research*, vol. 45, no. 1, pp. 64–73, 2005.

[77] F. Kanampiu, D. Makumbi, E. Mageto et al., "Assessment of management options on striga infestation and maize grain yield in Kenya," *Weed Science*, vol. 66, no. 4, pp. 516–524, 2018.

[78] S. K. Kim, V. O. Adetimirin, C. Thé, and R. Dossou, "Yield losses in maize due to *Striga hermonthica* in West and Central Africa," *International Journal of Pest Management*, vol. 48, no. 3, pp. 211–217, 2002.

[79] H. J. Bouwmeester, C. Roux, J. A. Lopez-Raez, and G. Bécard, "Rhizosphere communication of plants, parasitic plants and AM fungi," *Trends in Plant Science*, vol. 12, no. 5, pp. 224–230, 2007.

[80] R. J. Carsky, D. K. Berner, B. D. Oyewole, K. Dashiell, and S. Schulz, "Reduction of striga hermonthica parasitism on maize using soybean rotation," *International Journal of Pest Management*, vol. 46, no. 2, pp. 115–120, 2000.

[81] J. A. Odhiambo, B. Vanlauwe, I. M. Tabu, F. Kanampiu, and Z. Khan, "Effect of intercropping maize and soybeans onStriga hermonthicaparasitism and yield of maize," *Archives of Phytopathology and Plant Protection*, vol. 44, no. 2, pp. 158–167, 2011.

[82] H. Fourie, D. de Waele, A. H. McDonald, C. Mienie, M. Marais, and A. de Beer, "Nematode pests threatening soybean production in South Africa, with reference to *Meloidogyne*," *South African Journal of Science*, vol. 111, no. 9/10, pp. 2014–2212, 2015.

[83] A. Chabi-Olaye, C. Nolte, F. Schulthess, and C. Borgemeister, "Effects of grain legumes and cover crops on maize yield and plant damage by *Busseola fusca* (Fuller) (Lepidoptera: noctuidae) in the humid forest of southern Cameroon," *Agriculture, Ecosystems & Environment*, vol. 108, no. 1, pp. 17–28, 2005.

[84] R. Early, P. González-Moreno, S. T. Murphy, and R. Day, "Forecasting the global extent of invasion of the cereal pest *Spodoptera frugiperda*, the fall armyworm," *NeoBiota*, vol. 40, pp. 25–50, 2018.

[85] J. T. Hardke, G. M. Lorenz III, and B. R. Leonard, "Fall armyworm (Lepidoptera: Noctuidae) ecology in southeastern cotton," *Journal of Integrated Pest Management*, vol. 6, no. 1, p. 10, 2015.

[86] D. R. Sosa-Gomez, "Chapter 13—microbial control of soybean pest insects and mites," *Lawrence Lacey, Microbial Control of Insect and Mite Pests*, Academic Press, Cambridge, MA, USA, 2013.

[87] N. Mango, C. Makate, L. Mapemba, and M. Sopo, "The role of crop diversification in improving household food security in central Malawi," *Agriculture & Food Security*, vol. 7, no. 1, p. 7, 2017.

[88] E. Galasso and A. Wagstaff, *Economic Costs of Stunting and How to Reduce Them*, World Bank Group Policy Research Note, Washington, DC, USA, 2016, https://www.worldbank.org/en/research/brief/policy-research-note-no5-the-economic-costs-of-stunting-and-how-to-reduce-them.

[89] A. J. Stein, "Global impacts of human mineral malnutrition," *Plant and Soil*, vol. 335, no. 1-2, pp. 133–154, 2010.

[90] X. Wang and K. Taniguchi, "Does better nutrition enhance economic growth? The economic cost of hunger," in *Nutrition Intake and Economic Growth*, Food and Agriculture Organization of the United Nations, Rome, Italy, 2003, http://www.fao.org/3/y4850e/y4850e00.htm.

[91] P. D. Goldsmith, J. Andrade, M. Cornelius, M. Asigbee, P. Atiim, and C. Tamimie, "National school lunch nutrition and cost profile: a case study of the Ghana School Feeding Programme," *Food and Nutrition Bulletin*, vol. 40, no. 1, pp. 41–55, 2019.

[92] M. Amare, J. D. Cissé, N. D. Jensen, and B. Shiferaw, *The Impact of Agricultural Productivity on Welfare Growth of Farm Households in Nigeria: A Panel Data Analysis*, FAO, Rome, Italy, 2017.

[93] A. Irz and R. Tiffin, "Is agriculture the engine of growth?" *Agricultural Economics Journal*, vol. 35, pp. 79–89, 2006.

[94] M. Ravallion and G. Datt, *When is Growth Pro-Poor? Evidence from the Diverse Experiences of India's States*, World Bank, Washington, DC, USA, Policy Research Working Paper 2263, 1999.

[95] E. Martey, N. Gatti, and P. D. Goldsmith, "Assessing the performance of regional soybean prices in Ghana," *International Food and Agribusiness Management Review*, vol. 23, no. 2, pp. 267–282, 2020.

[96] FAO, *The Role of Soybean in Fighting World Hunger*, FAO Commodities and Trade Division, Basic Foodstuffs Service, Rome, Italy, 2004.

[97] J. O. Ojiem, N. De Ridder, B. Vanlauwe, and K. E. Giller, "Socio-ecological niche: a conceptual framework for integration of legumes in smallholder farming systems," *International Journal of Agricultural Sustainability*, vol. 4, no. 1, pp. 79–93, 2006.

[98] P. J. M. Cooper, J. Dimes, K. P. C. Rao, B. Shapiro, B. Shiferaw, and S. Twomlow, "Coping better with current climatic variability in the rain-fed farming systems of Sub-Saharan Africa: an essential first step in adapting to future climate change?" *Agriculture, Ecosystems & Environment*, vol. 126, no. 1-2, pp. 24–35, 2008.

[99] K. Abera, O. Crespo, J. Seid, and F. Mequanent, "Simulating the impact of climate change on maize production in Ethiopia, East Africa," *Environmental Systems Research*, vol. 7, no. 1, p. 4, 2018.

[100] A. Dale, C. Fant, K. Strzepek, M. Lickley, and S. Solomon, "Climate model uncertainty in impact assessments for agriculture: a multi-ensemble case study on maize in Sub-Saharan Africa," *Earth's Future*, vol. 5, no. 3, pp. 337–353, 2017.

[101] J. Rurinda, M. T. van Wijk, P. Mapfumo, K. Descheemaeker, I. Supit, and K. E. Giller, "Climate change and maize yield in Southern Africa: what can farm management do?" *Global Change Biology*, vol. 21, no. 12, pp. 4588–4601, 2015.

[102] U. Adhikari, A. P. Nejadhashemi, and S. A. Woznicki, "Climate change and eastern Africa: a review of impact on major crops," *Food and Energy Security*, vol. 4, no. 2, pp. 110–132, 2015.

[103] E. M. Zwane and K. E. Davis, "Extension and advisory services: the African renaissance," *South African Journal of Agricultural Extension*, vol. 45, no. 1, pp. 78–89, 2017.

[104] P. D. Goldsmith, "The faustian bargain of commercial crop agriculture in Africa," *Tropical Conservation Science*, vol. 10, pp. 1–4, Article ID 194008291772389, 2017.

[105] K. Ragsdale, M. R. Read-Wahidi, T. Wei, E. Martey, and P. D. Goldsmith, "Using the WEAI+ to explore gender equity among smallholder farmers: baseline evidence from Ghana's northern region," *Journal of Rural Studies*, vol. 64, pp. 123–134, 2018.

[106] S. K. Wambugu, J. T. Karugia, and W. Oluoch-Kosura, "Technology use, gender, and impact of non-farm income on agricultural investment: an empirical analysis of maize production in two regions of Kenya," *Agriculture, Diversification, and Gender in Rural Africa: Longitudinal Perspectives from Six Countries*, pp. 216–232, Oxford University Press, Oxford, UK, 2018.

[107] C. E. Sachs, *Gendered Fields: Rural Women, Agriculture, and Environment*, Routledge, Abingdon, UK, 2018.

[108] K. Ragsdale, R. Kobila, K. Clark, and M. Read-Wahidi, *Benefits of Women-Led Thresher Micro Enterprises in Rural Ghana*, USAID, Washington, DC, USA, USAID Feed the Future Newsletter, 2020.

[109] Soybean Innovation Lab (SIL), *SIL's Low-Cost, Locally-Produced and Locally-Serviced Thresher Webinar*, USAID Soybean Innovation Lab, Urbana, IL, USA, 2019, http://soybeaninnovationlab.illinois.edu/sils-low-cost-locally-produced-and-locally-serviced-thresher-webinar.

[110] S. O. Oikeh, P. Houngnandan, R. C. Abaidoo et al., "Integrated soil fertility management involving promiscuous dual-purpose soybean and upland NERICA enhanced rice productivity in the Savannas," in *Innovations as Key to the Green Revolution in Africa*, pp. 553–562, Springer, Dordrecht, Netherlands, 2011.