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].
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 sequentially 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]. Agroecological 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
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 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].
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

![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].](image1)

![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].](image2)
need for annual applications of phosphorus to the cereal, and biennial 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\textsuperscript{−1} [48]. Interestingly, while the literature is clear about planting soybean densely to assure maximum yield and a canopy for weed suppression (see Ajakporise 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]; Awumi 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 "safinha" 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 ha\(^{-1}\)/year of nitrogen in tropical settings [71] and then subsequently making available between 0 and 170 kg 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 its 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 of 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...
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].

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 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].

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

| 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.
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 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].
For example, women provide almost all of the labor for hand threshing soybean, a laborious process that 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.
institutions, and socioeconomic realities. Research which adapted to their production, infrastructure, and private and/or public extension services to better handle the socioeconomic conditions, such as labor and uncertainty associated with a new commercial crop like soybean. 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. 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.

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