# Chapter 12
# Integrated Farming Management Practices in Sub-Saharan Africa: Toward a Sustainable African Green Revolution

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**Abstract** This study investigates the possibilities and limitations of integrated farming management practices, such as sustainable intensification, integrated soil fertility management, climate-smart agriculture (CSA), and conservation agriculture (CA) in Sub-Saharan Africa (SSA), based on a literature review. We first introduce the concept of these practices as a means to improve land productivity while maintaining agricultural sustainability. Subsequently, we show the adoption determinants and their effects based on recently published empirical studies in SSA. Finally, we conclude with the policy implications and research agenda to disseminate optimum integrated farming management practices and achieve a sustainable African Green Revolution in SSA.

## 12.1 Introduction

Sub-Saharan Africa (SSA) still suffers from poverty and food insecurity as 40% of its population live below the USD 1.90-a-day poverty line in 2018, and 24% were undernourished in 2020. This is the highest prevalence of poverty and hunger in the world (FAO et al. 2021; Schoch and Lakner 2020). Many poor and undernourished people live in rural areas and engage in small-scale agriculture (Sibhatu et al. 2015). The agriculture of most rural farm households in SSA depends on small-scale crop and livestock production systems (Haile et al. 2017). Common characteristics of their farming are low productivity, low adoption rates of improved technologies, and vulnerability to climate and price shocks (Otsuka and Muraoka 2017). Therefore, a sustainable African Green Revolution is necessary for rural small-scale farmers in the SSA to escape poverty and food insecurity.

The adoption of yield-enhancing technologies is necessary to improve land productivity. However, the global consensus is that just adopting modern technology,

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such as improved varieties and inorganic fertilizers, is not enough to improve the productivity and profitability of rural smallholder farming in SSA in the long-run (Peterson and Snapp 2015; Pingali 2012). One reason for this is soil degradation. Soil degradation is a great challenge, especially in SSA, because increasing population pressure on land leads to a reduction in fallows and more continuous farming, which, in turn, depletes soil nutrients (Drechsel et al. 2001; Tittonell and Giller 2013). Using data from western Kenya, Marenya and Barrett (2009) empirically demonstrate that maize yield response to nitrogen fertilizer application is low when soil organic matter (SOM) is low. The low response rate to nitrogen application results in low profitability from the use of inorganic fertilizer (Burke et al. 2019). Therefore, it is important to replenish soil nutrients and maintain soil fertility in smallholder farmlands to achieve a high yield response rate and profitability of inorganic fertilizer application.

Moreover, climate change is likely to harm productivity and exacerbate the volatility of smallholder farming in SSA, where cropping mostly depends on rainwater. It is estimated that temperature rise, variable rainfall, and frequent dry spells caused by climate change may result in a 10–20% decrease in crop yield by 2050 in most tropical and subtropical regions of SSA (Jones and Thornton 2009). Moreover, climate change may also bring new pests and crop diseases (IPCC 2014). Thus, adaptive strategies are necessary to minimize the damage caused by climate change.

Integrated farming management practices, composed of multiple agricultural technologies and management practices, have been gaining attention and are recommended by national and international organizations to address the abovementioned issues (FAO 2015; Takahashi et al. 2020). These technologies include modern yield-enhancing technologies, such as improved varieties and inorganic fertilizers, and natural resource-conserving technologies, such as organic fertilizers, legume intercropping or rotation, minimum tillage, permanent soil cover by crop residues, and soil and water management. These are expected to improve land productivity and farming sustainability while minimizing environmental damage. A growing body of literature focusing on the impacts and adoption determinants of integrated farming management practices has emerged in the last 5 years. In this study, we first aim to elucidate how we could diffuse these technologies and practices in SSA by examining the adoption determinants found in the literature. Subsequently, we attempt to determine the effects of these factors on farm productivity, income, and food security by reviewing recent empirical studies. Thus, this study clarifies how we can promote optimum integrated farming management practices among rural small-scale farmers in SSA.

## 12.2 What Are Integrated Farming Management Practices?

Integrated farming management practices aim to improve land productivity and profitability in the long run without deteriorating the local environment. These types of integrated farming management practices, which are sustainable (agricultural) intensification (practices) (SI), integrated soil fertility management (ISFM), climate-smart agriculture (CSA), and conservation agriculture (CA).

SI could be defined as the process of raising land productivity without adverse environmental impacts (Pretty et al. 2011; The Montpellier Panel 2013). SI has five main domains: productivity, economic sustainability, human well-being, environmental sustainability, and social sustainability (Petersen and Snapp 2015; Smith et al. 2017). Although SI does not refer to a specific set of agricultural inputs or management practices (Kim et al. 2021), it usually consists of yield-enhancing technologies, such as improved seeds and inorganic fertilizers, and resource-conserving technologies, such as legume intercropping or rotation, use of organic fertilizers and crop residues, and minimum tillage (Manda et al. 2016; Pretty et al. 2011). The components of SI vary depending on local contexts and individual farmers' preferences (Kassie et al. 2013).

Although ISFM is pretty similar to farm management practices with SI, it focuses more on soil management. ISFM utilizes inherent soil nutrient stocks, locally-available soil amendments, and modern technologies, such as chemical fertilizers and improved seeds, to enhance crop yield while maintaining soil fertility (Vanlauwe et al. 2015).

CSA is an approach similar to SI, but it is a more adaptive strategy against climate change. CSA generally has three goals: (1) enhancement of productivity, (2) adaptation and building resilience to climate change, and (3) reduction of greenhouse gas (GHG) emissions (FAO 2017; Lipper et al. 2014). It also has components similar to SI, and the components change depending on the local context. Amadu et al. (2020) classified farm-level CSA practices into six categories, organized from least to most resource-intensive: (1) residue addition or application to soil, (2) non-woody plant cultivation, (3) assisted regeneration, (4) woody plant cultivation, (5) physical infrastructure, and (6) mixed measures.

CA is an approach similar to CSA. It achieves long-term productivity and environmental benefits by adopting three approaches: (1) minimum tillage, (2) permanent soil cover by crop residues, and (3) crop rotation (FAO 2022).

In the remainder of this section, common technologies and integrated farming management practices, such as SI, ISFM, CSA, and CA, are introduced.

### *12.2.1 Improved Seeds*

The diffusion of improved varieties is considered the most important means of boosting crop yield and improving the well-being of farmers in developing countries (Evenson and Gollin 2003). Previous studies have found that the adoption of improved crop varieties increases yield, crop and household income, consumption, and child nutrition (Bezu et al. 2014; Zeng et al. 2015, 2017). Adopting improved varieties is an important component of SI (Wainaina et al. 2018), ISFM (Horner and Wollni 2021), and CSA (Teklewold et al. 2019).

### 12.2.2 Inorganic Fertilizer

Inorganic fertilizer application is another important yield-enhancing technology in integrated farming management practices such as SI, ISFM, and CSA. The combined use of improved seeds and inorganic fertilizers is widely recommended in SI (Wainaina et al. 2018), ISFM (Horner and Wollni 2021), and CSA (Teklewold et al. 2019) because the use of inorganic fertilizers is necessary to gain the full yield potential of improved varieties. The joint use of improved seeds and inorganic fertilizers is the core of the Asian Green Revolution (Johnston and Cownie 1969).

### 12.2.3 Organic Fertilizers

Organic fertilizers usually include animal manure and composted crop residues and do not include crop residues retained on farmland (Scognammillo and Sitko 2021). They are expected to provide the soil with carbon, nitrogen, and phosphorous and enhance water retention under low precipitation (Ngwira et al. 2014). A typical method to implement SI, ISFM, and CSA involves the simultaneous application of inorganic and organic fertilizers. Kajisa and Palanichamy (2011) use household panel data in India and empirically demonstrate that applying organic fertilizers improves the marginal product of inorganic fertilizers, especially in soils with low fertility.

### 12.2.4 Intercropping/Rotation with Legumes

Another common practice is intercropping or rotation with legumes. Legumes fix nitrogen from the air and supply it to the soil (Mhango et al. 2013). They can also enhance crop yield sustainably by reducing plant diseases, weeds (e.g., Striga), and insects and increasing soil carbon content (Hutchinson et al. 2007; Manda et al. 2016). Additionally, crop diversification through intercropping or legume rotation can reduce production and market risks (Rusinamhodzi et al. 2012). Amare et al. (2012) empirically show that maize–pigeon pea adoption significantly increased income and consumption using household data from Tanzania.

### 12.2.5 Zero or Minimum Tillage

Zero or minimum tillage is one of the core components of CA because conventional tillage may lower SOM, the density of microorganisms and fauna in the soil, and its water-holding ability, and increase susceptibility to erosion and evaporation from the soil surface (Montt and Luu 2020).

### 12.2.6 *Permanent Soil Cover by Crop Residues*

Permanent soil cover by crop residues improves soil fertility and moisture retention and increases SOM (Manda et al. 2016). It is often combined with minimum tillage to enhance soil aeration and fertility, carbon sequestration, and water-holding capacity (Hobbs et al. 2008). Rusinamhodzi et al. (2012) found that minimum tillage can positively affect light-textured soil in low-rainfall environments when combined with retaining crop residues.

## 12.3 Adoption Determinants of Integrated Farming Management Practices

Although national and international organizations have attempted to diffuse integrated farm management practices, their adoption rates remain low in SSA (Arslan et al. 2015; Kassie et al. 2013; Teklewold et al. 2013a). Empirical studies using SSA data find that assets, nonfarm income, age, education, gender, labor availability, experience, social capital and networks, social safety nets, access to extension services, markets and credits, physical characteristics of plots, and soil characteristics affect the adoption of SI, ISFM, CSA, and CA (Arslan et al. 2014; Ehiakpor et al. 2021; Kassie et al. 2013, 2015a; Manda et al. 2016; Matoke et al. 2019; Mutenje et al. 2019; Teklewold et al. 2013a, b, 2019; Zeweld et al. 2020).

Several studies have revealed that weather variability, such as erratic rainfall or drought, accelerates the adoption of drought-tolerant maize, maize-legume intercropping, minimum tillage, use of crop residue as soil cover, and soil and water conservation technologies, such as stone bunds (Arslan et al. 2014; Asfaw et al. 2016; Issahaku and Abdulai 2020; Mutenje et al. 2019). This suggests that farmers use these technologies as adaptive strategies to mitigate climate change risk.

Tenure security is another key determinant in adopting SI, ISFM, CSA, and CA technologies. It takes time to receive the return on investment in several soil-conserving technologies, such as using organic fertilizers, minimum tillage, and permanent soil cover by crop residues. Thus, farmers do not have an incentive to invest in these technologies if they are unsure whether they can use the plots in the future. Using data from Kenya, Nkomoki et al. (2018) found that farmers with customary land tenure had 17.4, 17.2, and 9.1% lower probabilities of adopting legume intercropping and agroforestry and planting basins, respectively, than those with statutory tenure.[1] Other studies also found that tenure security enhances the

[1] Customary land belongs to traditional rulers (chiefs) in the community and its use rights are provided to villagers (Nkomoki et al. 2018). Since it has not received formal consent, there is no land tenure security. On the other hand, statutory land tenure secures exclusive ownership and protects from eviction by land title deed documents that guarantee full property rights on the land (Nkomoki et al. 2018).

adoption of SI, ISFM, CSA, and CA technologies (Ehiakpor et al. 2021; Kamau et al. 2014; Kassie et al. 2013; Teklewold et al. 2013b, 2019).

Different technology attributes and farmers' resource endowments result in different SI, ISFM, CSA, and CA technology adoption patterns. Adopting these technologies requires substantial labor, and it takes several years to realize their benefits (Jayne et al. 2019). For example, Schmidt et al. (2017) showed that soil and water conservation must be maintained for at least 7 years to significantly increase the value of production. Therefore, resource-rich farmers are more willing to make such investments than resource-poor farmers, who prioritize their immediate daily life needs (Jayne et al. 2019). Asfaw et al. (2016) stated that adopting crop residues as soil cover and organic fertilizers is characterized by low capital investments and high labor inputs, and results take time. On the other hand, inorganic fertilizers and improved seeds require high capital investments and low labor inputs but provide quick results. Thus, the difference in resource endowments and the needs of farmers are likely to result in different patterns of technology adoption.

## 12.4 Effects of Integrated Farming Management Practices

The actual effects of adopting these farming management practices are revealed only by empirical impact assessments using real data obtained from farmers' fields. This section aims to clarify the effects of adopting these measures by reviewing recent empirical studies using micro-level data (household or plot level) of SSA countries.

Empirical studies indicate that returns, (i.e., including crop yields, household income, and food security), are maximized when yield-enhancing modern technologies (e.g., improved seeds and inorganic fertilizers), and resource-conserving technologies (e.g., organic fertilizers, legume intercropping, minimum tillage, and soil and water conservation technologies), are adopted jointly (Kim et al. 2019; Khonje et al. 2018; Manda et al. 2016; Marenya et al. 2020; Mutenje et al. 2019; Teklewold et al. 2019; Wainaina et al. 2018). The solo adoption of resource-conserving technologies does not always bring positive returns. For example, a global meta-analysis conducted by Pittelkow et al. (2015) using 5,463 paired observations from 610 studies shows that zero tillage reduces yield compared to conventional tillage. However, they also show that if zero tillage is implemented with two other CA practices (crop residue retention and crop rotation), its adverse impacts are minimized. Furthermore, Vanlauwe et al. (2014) argued that in addition to three CA practices (minimum tillage, permanent soil cover by crop residues, and crop rotation), inorganic fertilizers could enhance organic residue availability and crop yield in SSA.

Studies revealed that resource-conserving technologies can reduce yield variability when farmers encounter weather shocks. Kassie et al. (2015b) elucidated that the joint adoption of crop diversification and minimum tillage reduced the downside risk in the maize yield in Malawi. Similarly, Zeweld et al. (2020) demonstrated that farmers facing unpredictable rainfall could significantly enhance agricultural production by adopting soil and water conservation and organic fertilizers in Ethiopia. Furthermore, Maggio et al. (2021) showed that adopting organic fertilizers and maize-legume intercropping would positively affect crop production, especially under extremely high-temperature deviations in Uganda. These evidences indicate that adopting resource-conserving technologies could be an adaptive strategy to mitigate the effect of climate change on smallholders in SSA. However, Arslan et al. (2015) found that the positive effects of inorganic fertilizers are lower under false rainfall onsets, and the positive effects of improved seeds vanish under very high growing season temperatures, which indicates that solo adoption of yield-enhancing technologies is insufficient to mitigate negative climate shocks.

## 12.5 Toward a Sustainable African Green Revolution

Given the population growth, limits of arable land expansion in SSA, and ongoing climate change, integrated farming management practices (i.e., SI, ISFM, CSA, and CA), which aim to improve land productivity while conserving natural resources, are being widely promoted by national and international organizations to improve smallholders' welfare and food security in SSA. This chapter attempts to elucidate adoption constraints and understand the actual effects of their adoption on farmers' farmlands by reviewing recent empirical studies.

Empirical studies based on smallholder data in SSA indicate that farmers could realize the maximum benefits of integrated farming management practices by adopting yield-enhancing and resource-conserving technologies in combination rather than in isolation. These studies also demonstrate that integrated farming management practices could mitigate climate shocks. Since these management practices are knowledge- and management-intensive, farmers' education and training through extension services are necessary to widely diffuse these practices among rural smallholders.

Farmers often need to wait several years to recover the investment benefits of integrated farming management practices. Therefore, land tenure security is important in incentivizing smallholders to make such long-term investments. Resource-rich farmers are more likely to make such investments than resource-poor farmers, who need to maintain their subsistence. Thus, access to credit should be guaranteed to make the adoption of these farming practices affordable even for the poorest farmers (Asfaw et al. 2016). Access to input and output markets should be developed to enable smallholders to obtain necessary inputs, such as improved seeds and inorganic and organic fertilizers, and sell their outputs.

It is important to understand that integrated farming management practices, such as SI, ISFM, CSA, and CA, are location-specific technologies, given the heterogeneity in soil, agroecological, input and output prices, and market conditions in various places. Hence, optimum integrated farming management practices should be developed and adjusted according to local situations and resource endowments. We expect that the productivity and profitability of integrated farming management practices could be further enhanced by investing in research and development, which would lead to a sustainable African Green Revolution in SSA.

Finally, we would like to point out that the available evidence is generally limited to the impact of integrated farming management practices on yield and income (Takahashi et al. 2020). Very few studies have analyzed profitability. This is problematic because complex knowledge-intensive technologies, such as SI, ISFM, CSA, and CA, which require care and judgment, are mainly performed by family labor. Although it is challenging to estimate profit because of the difficulty in imputing family labor costs, more research is needed to assess the profitability of new technologies. This is essential to determine their viability and scalability.

**Recollections of Professor Keijiro Otsuka**

I first met Professor Kejiro Otsuka in 2015 in a microeconomics class at the National Graduate Institute for Policy Studies (GRIPS). He then guided my dissertation while doing my Ph.D. studies at Michigan State University and supervised me while I was a postdoc in GRIPS. He guided me on the possibility of the Green Revolution in Sub-Saharan Africa with various micro-empirical research. His diligence and enthusiasm in his research on development economics to make the world a better place have greatly impacted me. It showed me how an empirical economist should be. I am honored and delighted to be his student and be part of the Festschrift to celebrate his tremendous accomplishments.

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