14 Integrated Soil Fertility Management Options for Sustainable Intensification in Maize-Based Farming Systems in Ghana

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Abstract

Declining soil fertility has become a major constraint affecting agricultural productivity in sub-Saharan Africa. Since 2000, several ISFM technologies have been introduced in SSA to address widespread soil degradation on the continent. While studies have shown that ISFM could contribute to increasing agricultural productivity in SSA, several institutional constraints continue to limit its use in the region. In this chapter we have shown how ISFM could contribute to increasing the productivity and profitability of agricultural production in maize-based farming systems in Ghana. We conclude with suggestions to design intercropping research involving grain legumes and cereals to optimise the system in terms of resource use and yield by exploiting legume genotypes that are high yielding and well adapted to intercropping systems.

Keywords

Agricultural productivity · Grain legumes · Mineral fertilizer · Organic resources · Technology

14.1 Introduction

Recent United Nation projections indicate that the world's population will hit 9.7 billion in 2050 (UN 2015). This requires increase in agricultural production to meet the demand for food, feed and fiber. In sub-Saharan Africa where most of the increase in population would occur, agriculture out-put would need to more than double by 2050 to meet increased demand for food, feed and fiber (FAO 2017).

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D. G. Panpatte, Y. K. Jhala (eds.), *Soil Fertility Management for Sustainable Development*, https://doi.org/10.1007/978-981-13-5904-0_14

Agriculture in sub-Saharan Africa (SSA) is however, mostly rain-fed and managed mainly by smallholders making it most vulnerable to climatic variability. Although over 80% of the population in the region directly depend on agriculture (World Bank 2008), SSA still rely on food imports to feed its people (Tadele 2017). In 2013 alone, 56.5 million tons of cereals (maize and wheat) and soybean, worth 18.8 billion USD were imported into the continent (Tadele 2017).

Yields of cereals in SSA are extremely low, averaging about 1.6 tons ha^{-1} compared to the global value of 3.9 tons ha^{-1} (Tadele 2017). This has been blamed on several factors including declining soil fertility, low use and limited access to mineral fertilizer and other improved production technologies (IFDC 2007; Tadele 2017) resulting in hunger, malnutrition and food insecurity. Mineral fertilizer use in sub-Saharan Africa is the lowest in the world averaging 8–10 kg ha^{-1} (IFPRI 2000). Use of mineral fertilizers in SSA is constrained by several factors including risks associated with rainfall variability, high cost and poor access and poor producer price (IFPRI 2000; Morris et al. 2007).

African smallholder farming systems are characterized by low-input agriculture that relies on the inherent organic matter content of the soil to sustain production (IFPRI 2000). While SOM can help in the maintenance of soil fertility by enhancing retention of soil nutrients and water-holding capacity of the soil, continuous cropping and soil erosion could reduce the level of organic matter in the soil thereby causing rapid decline in soil fertility.

Major effects of declining soil fertility include low crop yields, loss of agrobiodiversity, low water use efficiency in cropping systems and soil loss (Mapfumo et al. 2013). Farmers often respond to declining soil fertility and low crop yields through extensification, expanding their agricultural activities to non-agricultural lands. Thus, agricultural productivity in SSA cannot be achieved without soil fertility improvement (Morris et al. 2007).

In the 1960s and 1970s mineral fertilizers were promoted in SSA to increase agricultural production with the thinking that mineral fertilizer alone was sufficient to improve and sustain yields with organic resources playing a minimal role (Fairhurst 2012). The promotion of mineral fertilizers became the main thrust of extension advice from the 1960s onward with most donors and international development organizations playing a key role in promoting mineral fertilizer use (Hilhorst and Toulmin 2000). In the 1980s, use of organic resources was promoted (Vanlauwe et al. 2017) due to limited access to mineral fertilizers because of the structural adjustment program (SAP) and the removal of fertilizer subsidies in much of SSA. However, despite the huge investment made in the promotion of use of organic resources, particularly, green manure and legume trees, for soil fertility improvement, uptake has been very disappointing due to the initial investment needed to establish and plough back the material into the soil. From the 1990s onwards, combined use of mineral fertilizer and organic resources was promoted until 2000 onwards when it was widely recognized that significant improvement in soil fertility cannot be attained without combined use of mineral fertilizers and organic nutrient resources in the form of integrated soil fertility management (ISFM) (Vanlauwe et al. 2010; Bationo et al. 2011; Mapfumo 2011).

Since 2000, several ISFM technologies have been introduced in SSA to address widespread soil degradation on the continent. Studies have shown that ISFM could contribute to increasing agricultural productivity in SSA. This chapter focuses on how ISFM could make different contributions to increasing the productivity and profitability of agricultural production in maize-based farming systems in Ghana. We will first discuss the principles of ISFM. This will be followed by discussions on recent studies in ISFM in the Maize-based farming systems in Ghana and the optimal conditions necessary for uptake of ISFM technologies. We will conclude this chapter with further areas of ISFM research in Ghana.

14.2 Principles of Integrated Soil Fertility Management

Integrated soil fertility management is a set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop production (Vanlauwe et al. 2010, 2015). ISFM is based on three principles, namely combined application of fertilizer and organic resources; integration of improved germplasm for any improved strategy for nutrient management and good agronomic practices. According to Fairhurst (2012), these principles recognize that:

1. Neither practices based solely on mineral fertilizer nor soil organic resources are sufficient to sustain agricultural production
2. Well adapted, disease and/or pest resistant germplasm is necessary to make efficient use of available nutrients and
3. Good agronomic practices in terms of planting dates, planting densities and weeding are necessary to ensure efficient use of scarce nutrient resources.

The contributions of the various components that constitute ISFM to crop productivity have been discussed by Fairhurst (2012). According to Fairhurst (2012), organic resources (crop residues and animal manure) constitute an important source of nutrients in crop production. However, while the nitrogen (N), phosphorus (P), magnesium (Mg) and calcium (Ca) content of organic resources is only released and made available for crop use upon decomposition, potassium is often released rapidly because it is released from the cell sap. Moreover, the amount of nutrients contained in organic inputs is usually not sufficient to sustain the required level of crop productivity and obtain the full economic potential of a farmer's production resources. However, besides supplying nutrients, organic resources also contribute to crop growth in several ways including:

- Improving the crop response to mineral fertilizer;
- Enhancing moisture retention capacity of the soil;

- Regulating soil chemical and physical properties that affect nutrient storage and availability;
- Supplying other nutrients not contained in mineral fertilizers;
- Creating a favourable rooting environment
- Improving the availability of P and N for plant uptake;
- Ameliorating soil acidity problems and
- Replenishing soil organic matter

Mineral fertilizers are needed to supplement the nutrients recycled or added in the form of crop residues and animal manures. They are concentrated sources of essential nutrients in a form that is readily available for plant uptake. Based on the cost of the nutrients that they contain; mineral fertilizers are often less costly compared with organic inputs. Yet, they are often considered by farmers as being costly due to limited access to credit by smallholder farmers to purchase them.

ISFM places much emphasize on the use of crop planting materials best adapted to a particular farm environment in terms of responsiveness to nutrients, adaptation to the bio-physical environment and resistance to pest and disease. Improved varieties often have a larger harvest Index (HI) and a higher agronomic efficiency compared with the "unimproved varieties". In addition, some improved varieties have an extensive rooting system which enable them to exploit a larger soil volume for uptake of nutrients compared with unimproved varieties.

14.3 Integrated Soil Fertility Management Practices and Agricultural Productivity within the Maize-Based Farming System in Ghana

14.3.1 Maize-Based Farming System Environment in Ghana

The maize-based farming system in Ghana is a traditional farming system of the forest/savanna transitional and the Guinea Savanna zones of Ghana. Much of the maize-based farming system in the forest/savanna transitional zone used to be part of the tree crop farming system while much of the system covering part of the Guinea Savanna zone used to be noted to produce small grains (sorghum and millet) and rice.

The forest/savanna zone of the farming system used to be a major cocoa-growing area in the early 1940s. The presence of abundant natural resources, particularly fertile land and the booming cocoa industry in the area attracted migrant farmers from the northern part of Ghana and southern Burkina Faso into the zone either to cultivate cocoa or work on the cocoa farms as farm laborers. However, the 1982–83 bush fires across Ghana destroyed much of the cocoa farms in the area. An attempt to replant the cocoa in the area failed partly due to the increasing dryness and deforestation in the area. When it became difficult to replant the cocoa, they shifted to the production of food crops as an adaptation strategy (Adjei-Nsiah and Kermah 2012) and selected crops suitable for the new environment (Donatelli et al. 2000). Farmers resorted to the cultivation of maize, yams and cassava.

Much of the maize-based farming system area in the Guinea Savanna zone of Ghana used to be cropped to small grains (sorghum and millet) and rice. However, with the declining soil fertility and introduction of high yielding maize varieties which respond well to mineral fertilizers coupled with changing dietary pattern of the people and commercialization of agriculture, farmers gradually switched from the cultivation of rice and small grains to maize. Besides maize, other important crops grown in this zone include yam, sorghum, groundnut, cowpea and soybean.

The forest/savanna transitional zone of the maize-based farming system has a bimodal rainfall pattern that begins in April and ends in November with peaks in June/July and September/October. The rainy season is followed by a dry season from December to March. The annual rainfall amount is about 1300 mm. The soils in the area are mainly Lixisols and are mostly fragile with shallow and impermeable iron pans (Asiamah et al. 2000).

The Guinea Savanna zone has a unimodal rainfall pattern and occurs between May and October followed by a long dry season between November and April. Total annual rainfall amount is between 900 and 1113 mm. The soils are classified as Savanna Ochrosol and Groundwater Laterites in the interim Ghana Soil Classification System (Adjei-Gyapong and Asiamah 2002) and as Plinthosols according to the World Resource Base (WRB 2015). The soils are inherently low in fertility (Braimoh and Vlek 2004) expressed in low levels of organic carbon (OC), total nitrogen (N) and available phosphorus (P) (Table 14.1).

Soil total N and available P, the most limiting nutrients for both cereal and legume production in both the forest/savanna transitional and Guinea Savanna zones are very low (Table 14.1) and both N and P deficiencies are widespread. Fertilizer application in Ghana is very low averaging 8–10 kg/ha which is one of the lowest in Africa. While farmers may apply mineral fertilizers to maize, other important crops cultivated in the farming system such as legumes (cowpea, groundnut and soybean) and root and tubers (yam and cassava) hardly receive any fertilizer.

14.3.2 Effect of Integrated Soil Fertility Management on Crops Production

Research results in the maize-based farming systems in Ghana have shown the importance of ISFM in crop production (Adjei-Nsiah et al. 2007, 2008a, 2018; Ahiabor et al. 2014). In both the forest/savanna transitional and Guinea Savanna zones, nitrogen appears to be the most limiting nutrients and the use of N fertilizer in combination with organic resources have been found to increase both maize and cassava yields (Adjei-Nsiah et al. 2007, 2008a).

In the forest/savanna zone of Ghana, Adjei-Nsiah et al. (2007) reported that cropping sequences involving Mucuna and maize in which the maize received 60 kg N ha^{-1} resulted in 100% increase in maize grain yield compared with continues maize cropping. In the same trial, when the maize was preceded by pigeonpea,

Table 14.1 Means and ranges of selected physical and chemical properties of soils of the forest/savanna transitional and Guinea Savanna zones of Ghana

Parameter	Range	Mean
Forest/savanna transitional agro-ecological zone (N = 83)		
pH (H_2O 2:1)	5.43–7.54	6.18
Clay (%)	4.88–13.55	9.32
Sand (%)	59.13–87.02	72.06
Silt (%)	5.52–29.86	18.62
Organic carbon (%)	0.35–1.33	0.76
Total *N* (%)	0.03–0.13	0.07
Avail P mg kg^{-1}	2.76–62.73	16.58
Exchangeable cations (me/100 g)		
K	0.07–1.3	0.25
Ca	1.6–6.91	4.26
Mg	0.53–1.97	1.23
Na	0.05–0.52	0.12
ECEC	2.66–9.53	6.07
Guinea Savanna agro-ecological zone (N = 93)		
pH (H_2O 2:1)	6.03–7.33	6.89
Clay (%)	5.34–15.62	10.12
Sand (%)	57.58–84.31	68.4
Silt (%)	8.22–31.92	21.58
Organic carbon (%)	0.28–1.05	0.50
Total *N* (%)	0.02–0.09	0.05
Avail P mg kg^{-1}	0.72–21.85	6.01
Exchangeable cations (me/100 g)		
K	0.06–0.61	0.30
Ca	0.80–9.08	3.60
Mg	0.27–4.27	1.09
Na	0.03–0,31	0.13
ECEC	1.72–13.92	5.28

or cassava and 60 kg N ha^{-1} was applied to the maize, maize yield increased by about 95%. The large increase in yield of maize when rotated with cassava, mucuna or pigeonpea was attributed to the large amount of organic input incorporated in the soil just before planting the maize. The faster decomposition of the biomass and N release was better synchronized with maize demand. In a similar trial in the same location, Mapfumo et al. 2013 also evaluated ISFM technologies involving the application of N fertilizer and different cropping sequences with farmers. The different cropping sequences evaluated resulted in maize yields benefits ranging from 25% to 125%. Yields of maize were higher on plots previously cropped with cowpea, groundnut and pigeonpea compared with the control under continuous maize cropping or bush fallow.

Efficiency of ISFM technologies depends upon choice of crop variety, retention of legume residues, judicious application of mineral fertilizers and targeting fertilizer to specific phases of the rotation. Several studies (Adjei-Nsiah et al. 2008a;

Kanton et al. 2017; Kermah et al. 2018) in the forest/savanna and the Guinea Savanna zones of Ghana have shown yield benefits of legume/maize rotations on maize grain yields in recent times. In the forest/savanna transitional zone of Ghana, Adjei-Nsiah et al. (2008a) reported of significantly higher maize grain yield increases of between 100% and 150% when maize followed erect cowpea varieties and 275% increase when maize followed an indeterminate creeping cowpea variety compared to maize after maize. The erect cowpea varieties recorded N fertilizer equivalent values of between 18 and 23 kg N ha^{-1} while the indeterminate creeping variety recorded N fertilizer equivalent value of 60 kg N ha^{-1}.

In the northern Guinea Savanna zone of Ghana, Horst and Hardter (1994) showed that rotation of maize with cowpea improves yield and nutrient use of maize on an alfisol. In the same location Kanton et al. (2017) reported of yield increases of maize in soybean/maize rotations of between 1% and 46% when maize was preceded by soybean amended with mineral and/or organic fertilizer.

Integrated soil fertility management in grain legumes has also received research attention in the maize-based farming system in northern Ghana in recent times (Ahiabor et al. 2014; Lamptey et al. 2014; Aziz et al. 2016; Adjei-Nsiah et al. 2018). Widespread response of soybean to rhizobium inoculation and phosphorus application has been obtained in northern Ghana.

Several studies (Ahiabor et al. 2014; Lamptey et al. 2014; Adjei-Nsiah et al. 2018) in the Guinea Savanna zone of Ghana have demonstrated that soybean responds better to rhizobium inoculation when it is applied in combination with 30 kg of phosphorus. In the studies by Ahiabor et al. (2014), inoculation of soybean with rhizobium together with the application of 30 kg P ha^{-1} resulted in grain yield increase of about 122% compared with only 22% increase in grain yield with rhizobium inoculation alone. In the same location, Masso et al. (2016) also reported significantly higher yield increase in soybean grain when soybean seeds were inoculated with rhizobium inoculant and received 30 kg P ha^{-1}.

Similar observations have also been made by Adjei-Nsiah et al. (2018) in the Guinea Savanna zone of Ghana and by Ronner et al. (2015) in a similar environment in northern Nigeria. Phosphorus is known to play a major role in N fixation including legume-rhizobia symbiosis (Yacubu et al. 2010) besides its role in stimulating root growth.

14.4 Optimal Conditions for Uptake of ISFM Technologies

Studies in West Africa (Sterk et al. 2013) suggest that increasing the yield of smallholder farmers have limited impact on their livelihoods since they have few opportunities that can be captured through technologies alone. Africa farmers need “enabling conditions” such as functioning input and output market, access to functioning public research and extension service, rural infrastructure such as roads and market, regulatory framework that ensures a level playing field and access to credit (Adjei-Nsiah et al. 2013). Leeuwis and van Den Ban (2004) suggest that availability and/or functioning of institutions such as input system, output market, credit and land tenure should not only be regarded as conditions that enhance or constrain adoption of promising technologies but should also be regarded and treated as an integral component of agricultural innovation.

14.4.1 Investment in Infrastructure

To promote uptake of ISFM technologies, there is the need to provide key public goods such as public agricultural research and extension and road infrastructure. The diverse and complex nature of farming systems in Africa as well as severe biophysical conditions suggest that no single set of ISFM package could be appropriate for all environments (IFPRI 2000). A vibrant research and extension system is therefore vital for knowledge generation and transfer to farmers in diverse and complex environments. Investments in road infrastructure facilitate farmers access to both input and output market and reduce transportation cost.

14.4.2 Land Tenure

Land tenure systems affect investment in soil fertility management in smallholder farms. Studies (Adjei-Nsiah et al. 2004, 2008a) have shown that secure land tenure is an incentive for smallholder farmers to invest in soil fertility management. If farmers do not have secure access to land, they may not be willing to invest in high cost, slow-repayment processes for rebuilding soil capital and reducing soil erosion. In the forest-savanna transitional zone of Ghana and Benin, Saidou et al. (2007) reported that immigrant farmers engaged in non-sustainable soil fertility management practices not because they did not understand soil fertility but because insecure tenure contracts made them reluctant to invest in soil fertility improvement. In the forest/savanna transitional zone, it became necessary to create platform of landowners, immigrant farmers and traditional authorities to negotiate for more secure tenancy contracts (Adjei-Nsiah et al. 2008b). It is therefore important for government in SSA to implement landholding policies that guarantee long-term investment in soil fertility by farmers.

14.4.3 Input and Output Market

Studies have shown that use of inorganic fertilizer and improved germplasm are a prerequisite for maintenance of soil capital and increase in crop productivity. Thus, uptake of ISFM technologies could be hampered by poorly functioning input and output markets. Agricultural inputs such as fertilizers and improved planting materials must be available in local markets at the right time and at affordable prices. Functioning output market is very essential for uptake of ISFM technologies. If farmers cannot sell their produce this will serve as disincentives for them to invest in ISFM. In both Ghana (Adjei-Nsiah 2008a) and Benin (Saidou et al. 2008), ISFM researchers incurred the displeasure of farmers, after farmers could not market their surplus maize they had helped them to produce in the transitional zone of the two countries.

14.4.4 Access to Credit

Access to credit by smallholder farmers is important for uptake of ISFM technologies. If the cost of ISFM recommended input is beyond the reach of farmers, farmers may need credit to procure them. However, most farmers, especially smallholder farmers do not have access to formal credit and therefore cannot afford to buy mineral fertilizers even where it has been proved beyond doubt that it is profitable (Obeng et al. 1990). In most parts of Africa, credit obtained by farmers for their farming activities is from the informal sector with interest rates ranging from 30% to 100%.

Conclusion

This section summarizes the role of ISFM in enhancing the productivity of the maize-based farming system in Ghana. It also summarizes contributions of research in ISFM to sustainable intensification in the maize-based farming system in Ghana. Maize yields in smallholder farming systems hardly exceeds 2 tons per hectare but recent studies in ISFM suggest that integrated management options that integrates organic nutrient resources and inorganic fertilizers in the production of improved maize varieties could increase maize yields to about 3–4 tons per hectare. Research has also demonstrated the contribution of grain legumes in intensifying the production of maize in the maize farming systems of Ghana. Yield increases of between 100% and 275% have been recorded when maize follows cowpea compared with maize after maize.

Research has also demonstrated the contribution of rhizobium inoculation and P fertilizer to grain legume productivity. Yield increases as high as 120% have been obtained with soybean in studies involving the use of rhizobium inoculant and P fertilizer in northern Ghana. While the use of rhizobium inoculant and P fertilizer may be agronomic effective, the use of P may not benefit a large section of the farming community in economic terms due to poor output/input price ratios of some grain legumes. Although ISFM plays important role in the sustainability of the maize-based farming system in Ghana, its uptake could be hampered by several institutional bottlenecks including land tenure, poor infrastructure, limited access to input and out-put market and credit.

Future Trends in ISFM Research

In most parts of the maize-based farming system in Ghana, grain legumes are either rotated or intercropped with cereals (Adjei-Nsiah et al. 2008a; Kermah et al. 2017a, b). However, yields of both legumes and cereals in the intercropped systems are often low (Kermah et al. 2017a, b). Thus, intercropping research involving grain legumes and cereals should be designed to optimise the system in terms of resource use and yield. One of the limitation to the adoption of cereal/maize intercropping is the limited access to high yielding legume varieties that are also well adapted to intercrop conditions (Tetteh et al. 2017). Future studies should exploit grain legume genotypes that are high yielding and well adapted to intercropping systems. Although smallholder farming systems in much of SSA are characterized by wide diversity of farming household and marked soil heterogeneity (Tittonell et al. 2005; Giller et al. 2011), the use of mineral fertilizers in the maize-based farming system in Ghana has been primarily promoted through blanket recommendation of N, P and K. There is also much inter- or intra- farm soil fertility variations that need to be accounted for in the blanket recommendation. There is therefore the need to develop site-specific fertilizer recommendation for the different maize-based farming system areas in Ghana. While N and P deficiencies are widely known to be widespread in the maize-based farming system in Ghana, very little is known about the extent of deficiencies of potassium (K) and secondary (Mg, Mg, S) and micro-nutrients (Zn, Mn, B and Mo) and their requirement for maize production. In soils of limited nutrient reserves, particularly sandy soils, K, Ca, Mg, Zn, Mn, B and Mo have been observed to limit crop growth (Vanlauwe et al. 2015). There is the need to initiate research to support the development of fertilizer blends containing K, Ca, Mg, S and micro-nutrients.

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