Andre Bationo · Djimasbé Ngaradoum
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Joseph Opoku Fening *Editors*

Improving the Profitability, Sustainability and Efficiency of Nutrients Through Site Specific Fertilizer Recommendations in West Africa Agro-Ecosystems

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Preface

The population in West Africa has quadrupled over the last 50 years, and this rapid growth has had a huge impact on the food demand and natural resources. Food production per capita has declined for the past several decades in West Africa, the only major region of the developing world where this has occurred. This trend is putting at stake the livelihoods of the poor in the region and poses a daunting challenge to rural communities and regional and national policy makers. Poor land use and management result in soil and water erosion, depleted soil fertility, desertification, and salinization, creating a spiraling decline in the productivity of the land for food and other ecosystem services. Nearly 3.3% of agriculture GDP is lost annually because of soil and nutrient losses. Soil fertility depletion is one of the major causes of declining per capita agricultural productivity and the consequent food insecurity in the region. Much research and extension effort in the past has been directed to promoting the adoption of improved crop varieties and fertilizers with an objective of generating technologies for the "African Green Revolution." However, adoption studies have shown limited uptake of external input-intensive technologies. In much of West Africa, the use of fertilizers and other purchased inputs is not sufficiently profitable to stimulate use by farmers in this market environment. Even where such inputs are profitable, they are often not used by farmers due to poorly developed markets, high production and market risks, cash and credit constraints, and other socioeconomic constraints

In 2016, two IFDC projects funded by USAID, the West Africa Fertilizer Program (WAFP) and C4CP, organized a West Africa regional workshop in response to the adoption of the regional fertilizer recommendation actions by ECOWAS in Lomé to review the state of the art of fertilizer recommendation in the region. It brought together over 100 participants from the public sector (technicians, researchers and academics, etc.), ECOWAS (Agricultural Department), key institutions in charge of soil fertility in West Africa, donor community (Islamic Development Bank (IsBD), ECOBANK, World Bank), farmers' organizations (ROPPA), and the private sector (fertilizer blenders, distributors, etc.). The objectives of the workshop were to capitalize on past and current fertilizer recommendations, validate an extrapolation methodology, and develop a roadmap for regional upscaling of updated fertilizer recommendations in West Africa.

Unfortunately, low productivity returns from unskilled use of fertilizer present a major impediment to their adoption by most small-scale farmers, and this requires an improvement in mineral fertilizer use efficiency. Past fertilizer recommendation was based on pan-territorial blanket recommendations. IFDC worked in West Africa in the past years with our national partners focused on improving the profitability, sustainability, and efficiency of nutrients through site-specific fertilizer recommendations. Our research activities on fertilizer recommendations were on looking for means to improve the agronomic efficiency of fertilizer (agronomic efficiency (AE) is defined as a ratio describing the increase in crop yield per unit of applied nutrients) within the framework of integrated soil fertility management (ISFM). The role of ISFM as a means to increase the efficiency of fertilizer nutrients by generating higher yield per unit of fertilizer added will accelerate farmers' adoption of fertilizers. Topics discussed in this workshop to increase fertilizer use efficiency include (1) the usefulness of organic soil amendment, (2) the use of improved crop cultivars, (3) the urea deep placement for paddy rice, (4) the strategic application of small quantities of fertilizers known in the West Africa region as the microdose technology that has the potential to transform the Sahel from gray to green, (5) balanced crop nutrition consisting of applying not only the macronutrients but also secondary and micronutrients where needed, and (6) water harvesting technologies to improve the nutrient use efficiency in the drylands.

The diversity of West African soils and climates limits the extrapolation of experimental results to wide geographic areas, and it is practically impossible to do experiments everywhere. In West Africa, climate change is widely expected to result in major changes in crop productivity and affect adversely the livelihoods of millions of people unless appropriate measures are taken. The use of soil and extrapolation models can enhance our understanding of environmental (climate, soils, and management) influences on the productivity of crops and inform the key decision-makers at local, national, and regional levels in order to put the appropriate measures in place. Models offer a cheaper means of understanding crop responses to management in different environments. We need to move away from the "trial-and-error" approach in agricultural research for evaluating management practices. We need a system approach in which (1) experiments are conducted over a range of environments, (2) a minimum set of data is collected in each experiment, (3) cropping system models are developed and evaluated, and (4) models are used to simulate production technologies under different weather and soil conditions so as to provide a broad range of potential solutions for farmers. The use of decision support systems such as the Decision Support System for Agrotechnology Transfer (DSSAT) is gaining momentum in the region, and its wider use with improved IT knowledge will improve the site-specific fertilizer recommendations for more efficient and profitable fertilizers.

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Chapter 1
Soil Organic Carbon and Proper Fertilizer Recommendation

Andre Bationo and J.O. Fening

Abstract Soil carbon in the form of organic matter is a key component of the soil ecosystem structure. In most parts of West Africa agro-ecosystems (except the forest zone), the soils are inherently low in SOC content due to low organic matter additions, and accelerated degradation. The rapid turnover rates of organic material is as a result of high soil temperatures and fauna activity particularly termites. The SOC levels rapidly decline with continuous cultivation. For the sandy soils, average annual losses may be as high as 4.7% whereas with sandy loam soils, losses are lower, with an average of 2.0%. To maintain food production for a rapidly growing population, application of mineral fertilizers and the effective recycling of organic amendments such as crop residues and manures are essential especially in the smallholder farming systems that rely predominantly on organic residues to maintain soil fertility. The efficiency of fertilizer use is likely to be high where the organic matter content of the soil is also high. In unhealthy or depleted soils, crops use fertilizer supplied nutrients inefficiently. Where soils are highly degraded, crops hardly respond to fertilizer applications. When SOM levels are restored, fertilizer can help maintain the revolving fund of nutrients in the soil by increasing crop yields and, consequently, the amount of residues returned to the soil. Crop yields can be increased by 20–70 kg ha^{-1} for wheat, 10–50 kg ha^{-1} for rice, and 30–-300 kg ha^{-1} for maize with every 1 Mg ha^{-1} increase in soil organic carbon pool in the root zone. There is need to increase crop biomass at farm level and future research should therefore focus on improvement of nutrient use efficiency in order to increase crop biomass.

Keywords Soil degradation • Crop productivity • Nutrient use efficiency • Soil organic matter • Smallholder farmer

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Contents

1.1 Introduction

Soil carbon in the form of organic matter is a key component of the soil ecosystem structure. The soil carbon content is an important contributing factor in the various flows and transformations of matter, energy and biodiversity - the essential soil functions that provide ecosystem services and life-sustaining benefits from soil. These goods and services include food production, water storage and filtration, carbon storage, nutrient supply to plants, habitat and biodiversity.

The natural soil carbon density is influenced by the balance between inputs (plant residues) and losses, mainly microbial decomposition and associated mineralization. This amount will vary with factors such as the specific land use undergoing change, soil type and texture, soil depth, bulk density, management and climate. Because of its superficial setting, small bulk density and organic constitution, soil organic carbon (SOC) is highly susceptible to water and wind erosion and chemical and physical degradation (Sombroek et al. 1993). The major drivers of SOC loss include demand for fuel, overgrazing, arable agriculture and other overexploitation of vegetation. The resulting depletion of the global SOC pool is estimated at 40–100 Pg.

Across the world, soil organic carbon (SOC) is decreasing due to changes in land use such as the conversion of natural systems to food or bioenergy production systems. The losses of SOC have impacted crop productivity and other ecosystem services adversely. In the past 25 years, one-quarter of the global land area has suffered a decline in productivity and in the ability to provide ecosystem services because of soil carbon losses (Bai et al. 2008). The situation is made worse in the tropical soils, which are considered as more risky because cropping is synonymous to nutrient removal in the already impoverished soils with insufficiently replenishment. There is considerable concern that, if SOM concentrations in soils are allowed to decrease too much, then the productive capacity of agriculture will be compromised. Soils exhibit different behaviour and as such we would expect to have different SOC levels. However, there is a general consensus among the scientists that a 2% soil carbon (3.5% SOM) as a critical level for soils below which potentially serious decline in soil quality will occur (Loveland and Webb 2003).

One of the grand challenges for society is to manage soil carbon stocks to optimize the mix of five essential services - provisioning of food, water and energy; maintaining biodiversity; and regulating climate. Scientific research has helped to develop an understanding of the general SOC dynamics and characteristics; the influence of soil management on SOC; and management practices that can restore SOC and reduce or stop carbon losses from terrestrial ecosystems. As the uptake of these practices has been very limited, it is necessary to identify and overcome barriers to the adoption of practices that enhance SOC. Actions should focus on multiple ecosystem services to optimize efforts and the benefits of SOC.

1.2 Soil Organic Carbon Management

Deficiency of SOM is widespread in tropical soils and particularly those under the influence of arid, semiarid and sub-humid climates due to the controlling influence of climatic factors on primary productivity and biomass decomposition. Since sustainability is not possible without equalizing the nutrient removals and additions, productivity declines steadily without application of fertilizers. In temperate regions, crop residues are routinely incorporated into the soil, but the practice of returning residues to the soil is practically non-existent in tropical regions. Thus, in the tropics, low organic matter additions as well as accelerated degradation and loss due to year round prevalence of biologically active temperature and moisture regimes leads to rapid reductions in SOM levels and consequently, reduced soil health due to the absence of the beneficial effects of the organic matter.

In general, the SOM content of tropical soils, when brought under cultivation, can fall to as low as about 30% of the original value of the uncultivated indigenous state, but most reports indicate about a 60% reduction after 10 years of cultivation. Katyal et al. (2001) documented such changes with arable cropping from long-term field experiments. In a virgin soil, SOM remained stable for 10 years after fertilizer application, but subsequently fell to about 40% of the initial value during the next 3 years. However, when manures and fertilizer were applied, the SOM level was stable for 25 years, thus illustrating the value of integrated use of organic and inorganic nutrient sources in stabilizing and maintaining SOM in cropping systems and ensuring sustainability regardless of the cropping system.

The quantity of organic carbon in soil and the quantity and type of organic inputs have profound impacts on the dynamics of nutrients. Soil organic matter itself represents a large reservoir of nutrients that are released gradually through the action of soil fauna and microorganisms: this is especially important for the supply of N, P and S to plants, whether agricultural crops or natural vegetation. Organic matter also modifies the behaviour and availability of nutrients through a range of mechanisms including increasing the cation exchange capacity of soil, thus leading to greater retention of positively charged nutrient ions such as Ca, Mg, K, Fe, Zn and many micronutrients.

In West Africa as the rest of the continent, removal of crop residues from the fields, coupled with a lower rate of macronutrient application compared to losses, has contributed to negative nutrient balances (Stoorvogel and Smaling 1990). For nitrogen as an example, whereas 4.4 million tons are lost per year, only 0.8 million

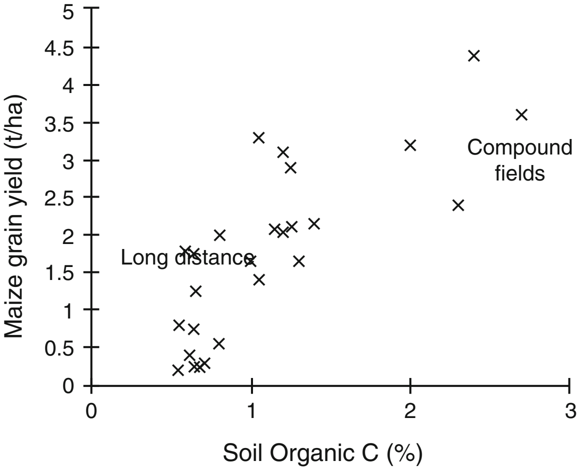

Fig. 1.1 Relationship between SOC content and maize grain yield for distant and compound fields in Northern Nigeria (Source: Carsky et al. 1998)

tons are applied (Bationo et al. 2004) (Fig. 1.1). Additionally, low and erratic rainfall, high ambient soil and air temperatures, inherent poor soil fertility, low water holding capacities and degraded soil structure lead to low crop productivity in this environment. Consequently, the present farming systems are not sustainable (Bationo and Buerkert 2001).

Transforming agriculture in West Africa agro-ecosystems and expanding its production capacity are prerequisites for alleviating rural poverty, household food deficits and environmental exploitation (Bationo et al. 2004).

Reversing the declining trend in agricultural productivity and preserving the environment for present and future generations in West Africa must begin with soil fertility restoration and maintenance (Bationo et al. 1996). Soil fertility is closely linked to soil organic matter, whose status depends on biomass input and management, mineralization, leaching and erosion (Roose and Barthes 2001; Nandwa 2001). It is well recognized that soil organic matter increases structure stability, resistance to rainfall impact, rate of infiltration and faunal activities (Roose and Barthes 2001). Optimum management of the soil resource for provision of goods and services requires the optimum management of organic resources, mineral inputs and the soil organic carbon (SOC) pool (Vanlauwe 2004). The importance of SOC has increased interest and research on its build up in the soil–plant system with current emphasis on conservation tillage. SOC can play an important role and its maintenance is an effective mechanism to combat land degradation and increase future food production. The SOM components such as humic molecules and polysaccharides increased aggregate stability by binding mineral particles into aggregates and reduced their susceptibility to erosion by wind or water (Tisdall and Oades 1982. In turn, formation of stable aggregates enhances physical protection of SOM against microbial decomposition (Six et al. 1998). Fertilizer additions also affect the chemical composition of soil solution which can be responsible for dispersion/flocculation of clay particles and thus, affects the soil aggregation stability (Haynes and Naidu 1998). Beneficial effects of increasing SOM concentration on enhancing soil structural stability have been widely documented (Barzegar et al. 1997). Reduction in SOM can degrade soil quality and fertility resulting in reduced agronomic productivity (Sharma and Subehia 2003). The SOM lowered the soil bulk density (Bronick and Lal 2005) and compaction (Dexter 1988), resulting in increased total porosity and water infiltration rate (Ndiaye et al. 2007).

Various farm practices have been employed to build SOC stocks in West Africa. Crop residue (CR) application as surface mulch can play an important role in the maintenance of SOC levels and productivity through increasing recycling of mineral nutrients, increasing fertilizer use efficiency, and improving soil physical and chemical properties and decreasing soil erosion. However, organic materials available for mulching are scarce due to low overall production levels of biomass in the region as well as their competitive use as fodder, construction material and cooking fuel (Lamers and Feil 1993). In a study to determine CR availability at farm level Baidu-Forson (1995) reported that at Diantandou in Niger with a long-term annual rainfall of 450 mm, an average of 1200 kg ha^{-1} of millet stover was produced at the end of the following year barely 250 kg ha^{-1} remained for mulching. Powel and Mohamed-Sallem (1987) showed that at least 50% of these large on-farm disappearance rates of millet stover could be attributed to livestock grazing. Animal manure has a similar role as residue mulching for the maintenance of soil productivity but it will require between 10 and 40 ha of dry season grazing and between 3 and 10 ha of rangeland of wet season grazing to maintain yields on 1 ha of cropland (Fernandez-Rivera et al. 1995). The potential of manure to maintain SOC levels and maintain crop production is thus limited by the number of animals and the size and quality of the rangeland. The potential livestock transfer of nutrients in West Africa is 2.5 kg N and 0.6 kg P ha^{-1} of cropland (de Leeuw et al. 1995).

Scarcity of organic matter calls for alternative options to increase its availability for improvement of SOC stock. Firstly, the application of mineral fertilizer is a prerequisite for more crop residues at the farm level and the maintenance of soil organic carbon in West African agro-ecosystems and therefore most research should focus on the improvement of nutrient use efficiency in order to offer to the smallholder farmers cost-effective mineral fertilizer recommendations. Secondly, recent success stories on increasing crop production and SOC at the farm level is as a result of the use of the dual purpose grain legumes having the ability to derive a large proportion of their N from biological N fixation, a low N harvest and substantial production of both grain and biomass. Legume residues can be used for improvement of soil organic carbon through litter fall, or for feeding livestock with the resultant manure being returned to the crop fields.

1.3 Soil Organic Carbon Status at Farm Level

SOC levels across fields on-farm show steep gradients resulting from long-term site-specific soil management by the farmer (Fig. 1.1). According to Prudencio (1993), SOC status of various fields within a farm in Burkina Faso showed great

Table 1.1 Carbon stocks of different subsystems in a typical upland farm in the Sudan-savanna zone

AEZ	pH (H_2O)	OC (g kg^{-1})
Home garden	6.7–8.3	11–22
Village field	5.7–7.0	5–10
Bush field	5.7–6.2	2–5

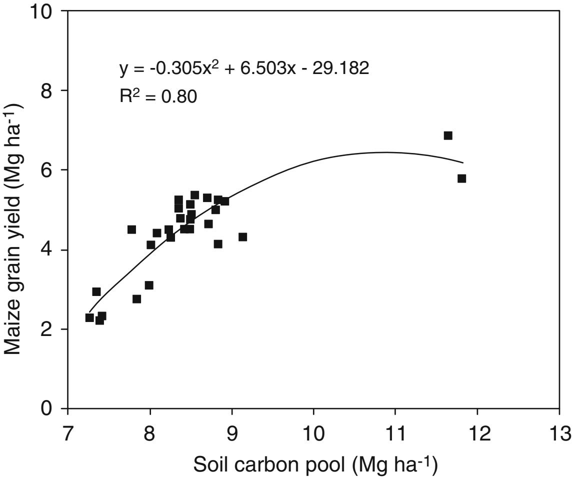

Fig. 1.2 Relationship between maize yield and soil organic carbon pool (Source: Brar et al. 2015)

variations with those of home gardens (located near the homestead) having 11–22 g kg^{-1} soil (Table 1.1), village field (at intermediate distance) 5–10 g kg^{-1} and bush field (furthest) having only 2–5 g kg^{-1}. Usually, fields closer to homesteads are supplied with more organic inputs as compared to distant fields. Manu et al. (1991) found that SOC contents were highly correlated with total N ($r = 0.97$) indicating that in the predominant agro-pastoral systems without application of mineral N, N nutrition of crops largely depends on the maintenance of SOC levels.

Crop yields increased by 490 kg ha^{-1} for maize wih every 1 Mg increase in SOC pool in the 0–15 cm depth under 100% NPK + FYM compared to 100% NPK treatment (Fig. 1.2). Lal (2006), also reported that crop yields increased by 20–70 kg ha^{-1} for wheat, 10–50 kg ha^{-1} for rice, and 30–300 kg ha^{-1} for maize with every 1 Mg increase in SOC pool in the surface 15 cm layer.

1.4 Fertilizer Use and Soil Organic Carbon Decline

Given the fundamental coupling of microbial C and N cycling, the dominant occurrence of both elements in SOM, and the close correlation between soil C and N mineralization, the practices that lead to loss of soil organic C also have serious implications for the storage of N in soil. Considerable evidence from

15 N-tracer investigations indicates that plant uptake is generally greater from native soil N than from N applied via fertilizers (Stevens et al. 2005). Thus, native soil N dictates the efficiency of applied fertilizer N as well as the quantity of N lost from the soil-plant system. Loss of organic N decreases soil productivity and the agronomic efficiency of fertilizer N and has been implicated in yield stagnation and the decline of grain production (Mulvaney et al. 2009). A decrease in soil N supply is inherently detrimental to productivity. Crop yields may be sustained or even increased by using improved varieties or due to higher fertilizer application rates despite the lower incremental return per unit of N applied, but eventually, soil degradation is likely to lead to a decline or stagnation in yield, an emerging concern for input-intensive agriculture. On the basis of the results of 45 long-term experiments ranging from 7 to 136 years in duration and mostly from temperate regions, Glendining and Powlson (1995) showed that long-term applications of N fertilizer increased total soil organic N as compared with treatments receiving no fertilizer N at 84% of the sites studied. On the other hand, in long-term experiments located in both temperate and tropical regions, continuous application of fertilizer N induced a net loss of soil organic N at 92% of the sites examined and a loss of soil organic C at 74%of the sites (Khan et al. 2007; Mulvaney et al. 2009).

Application of mineral fertilizer alone can cause decline in soil organic carbon. Pichot et al. (1981) reported from a ferruginous soil in Burkina Faso that with mineral fertilizer application, 25–50% of the indigenous organic matter disappeared during the first 2 years of cultivation. Bache and Heathcote, (1969), Mokwunye (1981), and Pichot et al., (1981) observed that continuous cultivation using mineral fertilizers increased nutrient leaching, lowered the base saturation and aggravated soil acidification. Also exchangeable aluminium was increased and crop yield declined. Application of organic material such as green manures, crop residues, compost, or animal manure can counteract the negative effects of mineral fertilizers (de Ridder and van Keulen 1990). This led Pieri (1986) to conclude that soil fertility in intensive arable farming in West Africa Semi-Arid Tropics (WASAT) can only be maintained through efficient recycling of organic material in combination with rotations of N2-fixing leguminous species and chemical fertilizers. In a long-term crop residue management trial in Sadore´, Niger during the 1996 rainy season, Bationo and Buerkert (2001) found that levels of SOC were 1.7 and 3.3 g kg^{-1}soil respectively, at 0.1 m for 2 ton ha^{-1} and 4 ton ha^{-1} of mulching with crop residue applied compared to unmulched plot (Fig. 1.3).

1.5 Conclusion

Soil organic carbon undoubtedly plays a key role in maintaining soil fertility and sustaining crop productivity in the soils in SSA. Given this importance, maintenance of an adequate level should be a guiding principle in developing management practices. However, just what constitutes an adequate level is likely to vary according to soil type, environmental conditions and farming systems. There are

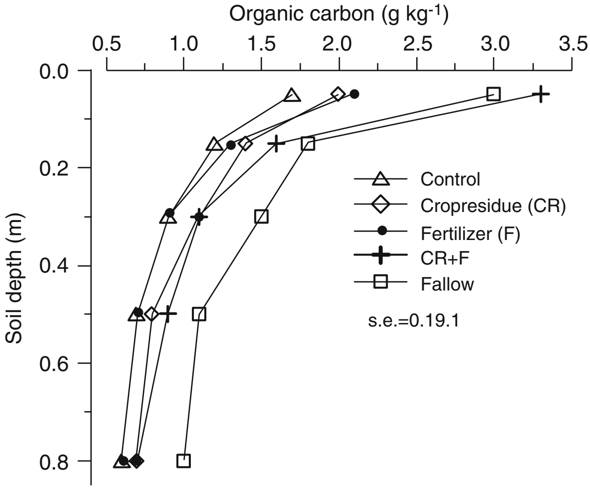

Fig. 1.3 Soil organic carbon (SOC) as affected by soil depth and management practices in Sadore´, Niger

numerous opportunities for improving soil carbon. Unfortunately the amount of organics available at farm level for use in soil improvement is limited by their alternatives uses as fuel, feed and fiber, and the labour required to collect and process these materials. Within most smallholder communities, the demand for animal manure is usually greater than its limited supply and in pastoral areas with substantial livestock, free grazing poses difficulties in collecting and transporting this important organic resource. These difficulties must not preclude the use of organic materials as inputs to soil but rather require that they be utilized in more labour efficient and cost effective ways. The use of inorganic fertilizer will remain an important option for increasing crop productivity and hence amount of residues available for the multiple uses among them soil improvement. The contribution of the organic resources to soil organic carbon will vary with the accompanying management and the quality of the resources. Integration of different qualities of organics is needed if the production objective is to achieve both immediate soil fertility and maintenance and crop improvement in the long term.

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Chapter 2
Nutrient Management in Livestock Systems in West Africa Sahel with Emphasis on Feed and Grazing Management

Augustine Ayantunde, Pierre Hiernaux, Salvador Fernandez-Rivera, and Mamadou Sangare

Abstract Feed and grazing management affect both the quantity and quality of animal manure and consequently nutrient cycling in the mixed crop-livestock systems in West Africa Sahel. Dietary measures can significantly influence the composition of manure and hence it's agricultural value. High nutrient feed will generally result in higher nutrient content of the manure whereas a decline in feed quality will generally lead to increase in the indigestible fractions in the feeds. Apart from feed and feeding practices, grazing management also affects the amount and nutrient contents of manure that can be recycled to the cropland. When animals are used to deposit manure in the crop field, conflicts often arise between the need for animals to graze long enough for adequate feed intake and the need to collect manure. This paper examines the effects of feed and grazing management on livestock-mediated nutrient transfers in mixed crop-livestock systems in West Africa Sahel. Results from grazing trials in Niger showed that nitrogen voided in faeces follow the trend of nitrogen contents in the feed for grazing cattle. Animals that had additional grazing time in the night consistently had higher forage intake and consequently, higher average daily gain than those that grazed only during the day in all seasons. However, additional grazing at night reduced the amount of

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manure that could be collected for crop fields unless the grazing location is crop field. It is therefore necessary to optimize the animals' time for foraging to maintain or increase livestock output in terms of meat and/or milk, and for manuring to sustain soil fertility and hence crop production.

Keywords Nutrient cycling • Animal nutrition • Grazing management • Crop-livestock systems • West Africa Sahel

Contents

2.1 Introduction

In the West African Sahel, livestock form a key element in food security strategies. They provide meat, milk, skins, draught power, transport and manure, and fulfill various socio-cultural functions such as payment of dowry, establishment and reinforcement of relationships and source of prestige within the pastoral society (Powell et al. 1996). For farmers and pastoralists livestock serve as a productive asset to generate income, reduce risks and mitigate the effects of drier than average years. Livestock provide an opportunity to invest surplus funds following a good crop harvest. In climatically unfavorable years, animals may be sold and the proceeds used to buy grain for human consumption. Livestock production in the Sahel is almost exclusively associated with exploitation of the rangelands and fallows. Animals are normally corralled on the crop field to deposit manure as one of the main soil fertility amendment strategies in West Africa Sahel (Williams 1999; Schlecht and Hiernaux 2004) in view of poor resource base of the farmers to procure inorganic fertilizers.

In addition to supply of animal products (meat, milk, hides and skin), ruminants play an important role in nutrient cycling in farming systems. Forage consumption by livestock accounts for a significant uptake of nutrients (organic matter, nitrogen and phosphorus) in mixed crop/rangeland-livestock systems in the tropics (Powell et al. 1996). For instance, Ayantunde (1998) reported that consumption by grazing cattle accounted for 46% of the annual production of organic matter (OM) by the Sahelian rangeland herbaceous above ground, and for 52 and 48% of the herbaceous uptake in nitrogen (N) and phosphorus (P), respectively. From the amount ingested 39, 40 and 42% of OM, N and P, respectively, was returned through fecal excretion. If urinary N is included, the fraction of N excreted may double. The role of grazing ruminants in nutrient cycling is even more important in view of spatial transfer of nutrients within the landscape and the associated losses. For example, through grazing nutrients are transferred by ruminants from fallow and rangeland to cropland. This has raised concern on the mining of nutrients from rangeland and the potential consequences on the long-term range productivity in the Sahel (Hiernaux 1993). In addition to the direct effect of nutrient harvest through consumption and returns via excreta (feces and urine) on nutrient cycling, the indirect effects that grazing and trampling have on soil, vegetation structure and floristic composition may even affect nutrient cycling more significantly (Hiernaux et al. 1998).

The types and amount of excreted nutrients available for recycling depend upon the livestock types and numbers kept by farmers, animal diet, watering regime, spatial and temporal distribution and voiding in the landscape. The proportion of N excreted in the urine and feces depends on the concentrations and degradability of the protein and the tannin content of the diet. Feeds with high protein content such as legumes are reported to result in higher proportion of N excreted in urine than in the feces (Minson 1990) due to their higher concentration of rapidly degradable protein and low concentration in rapidly degradable carbohydrates. Animal management, to a large extent, will also determine the amount of nutrients that are ultimately returned to the soil. For instance, by corralling the animals on the cropland, both manure and urine are returned to the soil, and losses during manure storage and transportation are reduced. Corralling also requires no labor for manure handling, storage, and spreading. For stall-fed animals, Powell et al. (1996) reported that over 40–60% of N in manure is lost. The nutrient cycling processes in crop-livestock systems are fraught with a lot of nutrient losses. Therefore major steps need to be put forth to reduce these losses particularly in storage/handling and application.

This paper examines the effects of feed and grazing management on livestock-mediated nutrient transfers in mixed crop-livestock systems in West Africa Sahel with the goal of identifying feed-related and grazing management strategies that can enhance nutrient cycling.

2.2 Materials and Methods

2.2.1 Data Sources

The data used for this paper come from three grazing trials carried out in Niger with different experimental designs between February 1995 and May 1997 with varied duration and timing of grazing. The data for the three grazing trials were pooled and re-analyzed in this paper. The first trial consisted of three treatments namely day grazing, night grazing and day-and-night grazing with 8 steers per treatment. The second trial consisted of 3 by 3 incomplete factorial design where 64 steers of average weight of 220 kg (standard deviation $= 78$) of the age between 16 and 24 months were allotted to eight treatments with 3 durations of grazing during the day (6, 9 and 12 h) and 3 durations of grazing during the night (0, 3 and 6 h). The number of treatments was eight instead of nine because the treatment with 12 h of grazing during the day and 6 h of grazing during the night was missing as this is not a common grazing practice. This trial was conducted in 1995 and 1996. In the third trial, 64 steers were allotted to eight treatments defined by two levels of supplementation with millet bran (0 and 608 g dry matter / day) and four durations of night grazing (0, 2, 4 and 6 h). The initial average weight of the steers was 224 kg (standard deviation = 58). All animals grazed for 10 h during the day. During the data collection periods (each data collection period lasted for 10 days), all animals were fitted with canvas bags to collect feces which were emptied in the morning before grazing and in the evening after return from day-time grazing. All animals were weighed every 2 weeks for three consecutive days during each grazing trial. The animals grazed in the same paddock during the day and at night. The details of experimental designs and results of the grazing trials have been reported by Ayantunde (1998) and Ayantunde et al. (2001).

To highlight the nutritional implications of corralling cattle on crop field in the night, the data of the grazing trials were pooled into two groups (day, and day-and-night grazing). Day grazing group represents absence of night grazing, that is, the animals are corralled to manure crop field while day-and-night grazing group typifies animals that are not corralled for manuring crop field.

In addition to the data collected from the grazing trials, we also used the data from on-station sheep feeding trials conducted in Sadore, Niger collected between 2000 and 2006 with different feed types and different levels offered in this paper. The data were used to show the effect of feed types and levels offered on fecal nitrogen and phosphorus, and urinary nitrogen output. Details of the feeding trials have been reported by Sangare (2002) and Ayantunde et al. (2007).

2.2.2 Data Analysis

Data collected from the grazing trials with cattle and feeding trials with sheep explained above were re-analyzed for the purpose of this study to examine the effects of feed and grazing management on livestock-mediated nutrient transfers in mixed crop-livestock systems. Data analyses were performed with Statistical Analysis Systems Institute (SAS 1987) using Means and TTest procedures for the data on body weight changes, forage intake and collectable manure of grazing steers for the day grazing, and day-and-night grazing groups. For the data on the feed types from sheep feeding trials, ANOVA procedure was used for variance analyses. Unless otherwise specified, the level of significance was declared at $p < 0.05$.

2.3 Results and Discussion

2.3.1 *Effect of Grazing Management on Forage Intake and Animal Performance*

Results from the grazing studies showed that night corralling, especially during the dry season, not only puts nutritional stress on the animals (by decreasing forage intake) and consequently results in reduced performance unless animals are supplemented. For instance, the animals that had additional grazing time in the night consistently had higher forage intake than those that grazed only during the day (Fig. 2.1) in all seasons. The positive relationship between grazing time and forage intake by grazing animals has also been reported by King (1983). Consequently, the day-and-night grazers had higher weight gains in the wet season and lower weight losses in the dry season than those that were corralled at night (Table 2.1). Similar results have been reported by Kyomo et al. (1972), and Wigg and Owen (1973).

2.3.2 *Effect of Grazing Management on Collectable Manure*

Additional grazing at night reduced the amount of manure that could be collected for crop fields (Fig. 2.2) unless animals are grazed on croplands. When the animals graze at night, the manure is deposited on the rangelands instead of crop fields where the manure is needed for crop production. In our studies, we found that

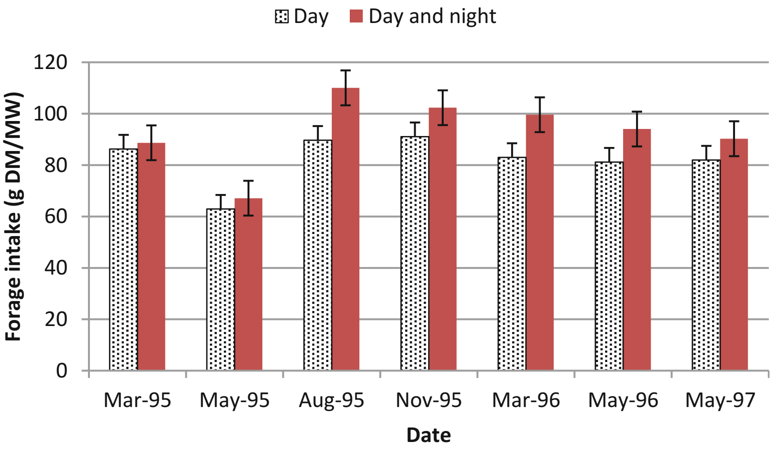

Fig. 2.1 Forage intake (g dry matter/metabolic weight/animal/day) of day grazing, and day-and-night grazing steers (age ranged between 16 and 24 months) on Sahelian rangeland. The values are averages from different grazing durations

Table 2.1 Average (±standard error) weight gain (g / animal / day) of day (i.e. night corralled) and day-and-night (i.e. not corralled) grazing cattle (age ranged between 16 and 24 months) on Sahelian rangelands

Date	Season	Day	Day-and-night
Feb. – May 95	Late dry	-435 ± 93^{a}	-239 ± 85^{b}
Jul. – Nov. 95	Wet/early dry	468 ± 23^{a}	512 ± 17^{a}
Feb. – May 96	Late dry	-238 ± 22^{a}	-176 ± 12^{b}
Apr. – June 97	Late dry	-191 ± 27^{a}	-79 ± 14^{b}

The level of significance for a,b is declared at $P < 0.05$

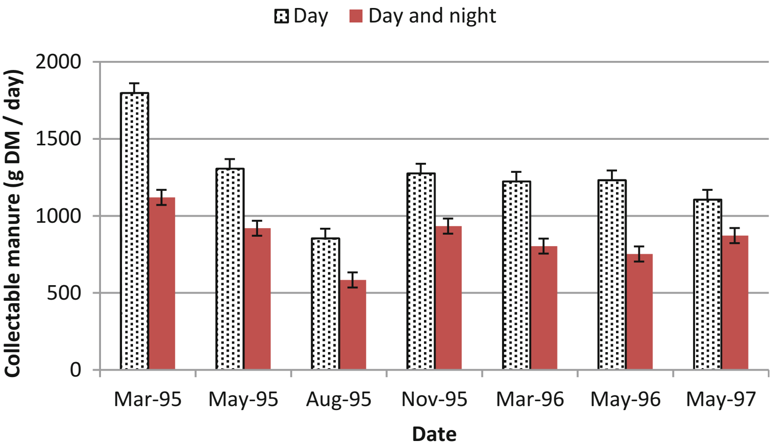

Fig. 2.2 Collectable manure (g dry matter/animal/day) of day grazing, and day-and-night grazing steers (age ranged between 16 and 24 months) on Sahelian rangeland. Collectable manure is defined as the amount of feces excreted while not in the pasture, i.e. the manure that could be collected through deposition while cattle are corralled on cropland

collectable manure decreased linearly with increase in duration of grazing, suggesting that more of the fecal output by the animals was deposited on the rangelands. The animals with the shortest grazing time (6 h only in the day) produced the highest amount of collectable manure, but had the lowest weight gain in both the wet and dry seasons (Ayantunde et al. 2001). Values for collectable manure ranged from 600 to 1800 g dry matter / animal /day). Collectable manure is defined as the amount of feces excreted while not in the pasture, i.e. the manure that could be collected through deposition while cattle are corralled on cropland. Except in the wet season (August 1995), manure from animals that were corralled at night (day grazing steers) exceeded 1 kg dry matter / animal / day (Fig. 2.2), whereas the day-and-night grazers produced less than this amount, except in March 1995, thus reaffirming the influence of animal management on amounts of manure available for cropping (Powell and Williams 1993; Williams 1999). In addition to animal management, type and number of animals, quantity and quality of the feed, and the animal production system affect the quality and quantity of available manure. In the

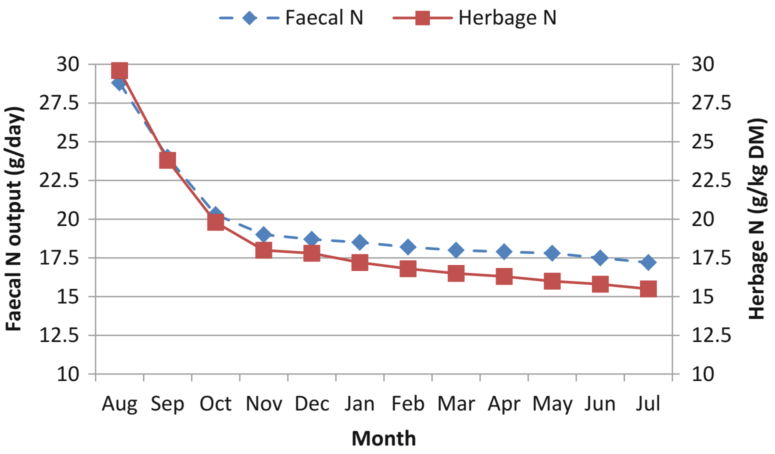

Fig. 2.3 Relationship between variation in herbage (pasture) nitrogen concentration (standard error = 6.8 g / kg DM) and fecal nitrogen output (standard error = 4.5 g/day) of unsupplemented grazing steer in Sahelian rangeland based on data collected from grazing trials in 1996 in Niger (Source: Ayantunde 1998)

pastoral systems in the Sahel, large amounts of manure are often deposited in non-productive areas such as at the vicinity of watering points, resting sites and along paths of animal movement.

2.3.3 Effect of Different Feed Types on Fecal Nitrogen and Phosphorus, and Urinary Nitrogen Output

Results from the grazing trials with steers showed that fecal nitrogen excretion followed the same trend as the nitrogen content of the pasture grazed along the seasons (Fig. 2.3). That is, the higher the nitrogen contents of the feed, the higher the amount excreted in feces. These results agree with results from feeding trials with sheep by Powell et al. (1994) which confirm that the total amount and proportion of nutrients voided in feces and urine is highly influenced by the nitrogen and phosphorus contents of the feeds. In addition to high amount of nitrogen excreted in feces for diet with high nitrogen content, there could also be large amount of urea excreted in urine (Romney et al. 1994; Delve et al. 2001) due to large amount of rapidly degradable proteins in the feed.

Results from feeding trials with sheep with different feed types and levels offered showed that nitrogen excretion in feces and urine was higher for diets that are rich in protein (groundnut cake and groundnut haulm) than for bush hay which is fibrous roughage (Table 2.2). Urinary nitrogen excretion of sheep fed diets containing groundnut cake was higher than for other diets because it had a high amount of rapidly degradable protein which would likely give rise to higher

Table 2.2 Effect of feed types and levels offered (g/kg Live weight) on fecal nitrogen and phosphorus (g/day), and urinary nitrogen (g/day) output for sheep (means ± standard error)

Feed type	Level offered (g/kg LW)	Fecal Nitrogen (g/day)	Fecal Phosphorus (g/day)	Urinary Nitrogen (g/day)
Bush hay	20	3.04 ± 0.16^{a}	0.96 ± 0.08^{a}	1.48 ± 0.19^{ab}
	40	3.12 ± 0.18^{a}	0.87 ± 0.06^{a}	1.71 ± 0.23^{ab}
	60	2.84 ± 0.22^{a}	0.92 ± 0.05^{a}	1.01 ± 0.18^{a}
	80	3.77 ± 0.17^{a}	1.14 ± 0.12^{a}	2.44 ± 0.21^{b}
Groundnut cake	0	4.08 ± 0.38^{a}	1.18 ± 0.08^{a}	1.32 ± 0.42^{a}
	2.5	3.92 ± 0.47^{a}	0.62 ± 0.06^{a}	3.31 ± 0.38^{b}
	5.0	4.57 ± 0.54^{a}	0.58 ± 0.07^{a}	3.28 ± 0.36^{b}
	7.5	6.32 ± 0.64^{b}	1.13 ± 0.11^{a}	6.73 ± 0.44^{c}
Groundnut haulm	0	4.41 ± 0.18^{a}	0.71 ± 0.09^{a}	1.43 ± 0.22^{a}
	5	4.52 ± 0.21^{a}	0.80 ± 0.11^{a}	1.62 ± 0.18^{a}
	10	5.03 ± 0.32^{a}	1.03 ± 0.08^{a}	2.57 ± 0.24^{b}
	15	4.95 ± 0.24^{a}	0.98 ± 0.10^{a}	3.24 ± 0.21^{b}

Data sources Sangare (2002) and Ayantunde et al. (2007)
The level of significance for a,b is declared at $P < 0.05$

excretion of nitrogen (urea) through urine and the associated increased loss via ammonia volatilization (Powell et al. 1994). The results also showed a generally low amount of phosphorus excreted through feces (Table 2.2). Phosphorus excretion is mainly through feces and this consists of two components, namely, the endogenous loss and excess phosphorus in the diet above the requirements of the animal (Barnett 1994). Urinary losses of phosphorus by ruminants are generally very low (Minson 1990). Increased excretion via urine only occurs when diets are relatively low in calcium or when animals are fasted and energy intake is restricted (Minson 1990) or when amounts of phosphorus absorbed are extremely high.

2.3.4 Feed and Grazing Management Factors Influencing Nutrient Cycling in Mixed Crop-Livestock Systems of West Africa Sahel

In Table 2.3, we present the main feed-related and grazing management factors influencing nutrient cycling in mixed crop-livestock systems in West Africa Sahel. The feed-related factors included feed type and amount offered, seasonal forage availability, feed fraction and digestibility, supplement feeding and feeding browse species. The grazing management factors included herding type, grazing itineraries, night grazing and night corralling practices. The effects of these factors are principally through manure quantity and quality, and the amount that could be

Table 2.3 Feed-related and grazing management factors influencing nutrient cycling in mixed crop-livestock systems in West Africa Sahel

Aspect	Factor	Possible effect	References
Feed and feeding system	Feed type and amount offered	Manure quantity and quality, partition of fecal and urinary nitrogen, excreted nutrient (nitrogen) loss via volatilization	Romney et al. (1994), delve et al. (2001) and Sangare et al. (2002)
	Seasonal availability	Manure quantity and quality, spatial distribution of deposited manure	Romney et al. (1994), Powell et al. (1996) and Williams (1999)
	Diet composition (nutrient content)	Fecal and urinary nutrient concentration, partition of fecal and urinary nitrogen	Powell et al. (1994) and Sangare et al. (2002)
	Feed fraction and digestibility(digestible and indigestible, degradability of dietary protein in the rumen)	Partition of fecal and urinary nitrogen, excreted nitrogen loss via volatilization	Powell et al. (1994) and Romney et al. (1994)
	Supplement feeding (protein rich supplement)	Manure quantity and quality, increased nitrogen excretion in urine, excreted nitrogen loss via volatilization	Sangare et al. (2002), Schlecht and Hiernaux (2004) and Ayantunde et al. (2008)
	Feeding browse species	Shifting excretion from urinary nitrogen to fecal nitrogen, less nitrogen loss via volatilization, more nitrogen in feces for recycling	Romney et al. (1994) and Delve et al. (2001)
Grazing management	Herding type (free ranging, close herding, tethered)	Manure quantity, nutrient transfer from rangeland to cropland	Hiernaux et al. (1998), Buerkert and Hiernaux (1998) and Schlecht and Hiernaux (2004)
	Stocking rate	Manure quantity	Powell et al. (1996), Schlecht and Hiernaux (2004)
	Grazing location	Manure quantity and quality	Hiernaux et al. (1998)
	Duration of grazing	Manure quantity	Ayantunde et al. (2001)
	Night grazing	Manure quantity	Ayantunde et al. (2001)
	Night corralling location	Manure quantity, nutrient loss	Schlecht and Hiernaux (2004)
	Timing and frequency of watering	Manure quantity, manure deposition around watering points and loss	Schlecht and Hiernaux (2004)

collected for crop field. Feeding protein rich supplement will generally increase nitrogen excretion in urine and loss via volatilization. Seasonal feed availability affects not just manure quantity and quality but also the spatial distribution of deposited manure because grazing itineraries vary markedly with seasons (Schlecht and Hiernaux 2004; Turner et al. 2005). Indigenous tree species are important sources of nitrogen for livestock as the season advances from wet to dry (Ayantunde et al. 2009). Feeding browse species will shift excretion from urinary nitrogen to fecal nitrogen, and this may result in less nitrogen loss via volatilization, which implies more nitrogen in feces for recycling. This suggests that a shift from urine nitrogen to fecal nitrogen, without adverse effects on animal performance could improve nutrient cycling in the mixed crop-livestock systems of West Africa Sahel (Powell et al. 1996). However, tannins in browse species can reduce dry matter intake and nitrogen digestibility which may affect the animals adversely. Besides, the presence of tannins in feeds has been shown to be negatively correlated with protein degradability and digestibility (Romney et al. 1994).

Herd management is quite important to spatial distribution of manure (Schlecht and Hiernaux 2004) as this determines when and where the animals graze, and consequently where manure is deposited. The location of watering points as well as frequency of watering also affects the amount of manure that could be collected. Where watering points are far away from the crop field, manure deposited around the watering locations is essentially lost for crops. The practice of grazing of residues on crop field after harvest is beneficial for manure deposition on the crop field (Bationo and Mokwunye 1991) and this is less demanding in terms of labor if the crop residues were to be harvested and taken to the homesteads to feed to the animals. Stall feeding generally imposes labor demand to collect and transport manure to the crop field. Besides, stall feeding has a high potential for nutrient loss as the nitrogen in urine is easily volatized (Powell et al. 1996).

2.3.5 *Feeding the Animals and Fertilizing the Soil*

In the West African Sahel as in other developing regions, livestock are kept to fulfill many functions, and not solely for manuring the crop field. Therefore, the need for manure collection for cropland cannot be considered independent of other production objectives. With this in mind, the approach to follow in addressing the conflict between adequate feeding of the animals through night grazing and night corralling to fertilize the soil is not choosing between either of the two practices, rather we should aim at identifying the optimal combination of the two practices. From our grazing trials with steers, we found that an appreciable amount of manure (about 1 kg dry matter / day) can still be collected from animals that graze during the night for 3 h in addition to 9 h during the day. This, however, requires additional labor for herding in the night, especially to secure return of the animals to the crop fields to be manured. In the early dry season when crop fields are open for livestock grazing, there may be no need for herding the animals in the night, if they are allowed to graze crop residues. Then, manure and urine are directly deposited on the cropland. Access to crop residue grazing, in return for manure deposition on the crop fields is the core of the manure contract, a common practice in semi-arid areas of West Africa (Toulmin 1992) and this helps to foster relationship between farmers and the transhumant pastoralists. The practice of the manure contract is however declining due to increase in harvest of crop residues for stall-feeding and/or for sale. Since grazing of crop residues can only be done for few weeks, herding labor for night grazing will still be needed in most of the dry season.

In the absence of herding labor for night grazing, so that the animals have to be corralled (i.e. not allowed to graze in the night), supplements have to be fed to ensure that their nutritional requirements are met and performance is not jeopardized, especially in the dry season. Results from our grazing trials on nocturnal grazing and supplementation show that length of night grazing time did not significantly affect average daily gain of supplemented steers. This suggests that night grazing even in the dry season is not necessary when animals are supplemented with at least 500 g dry matter of millet bran. However, night grazing may still be necessary, especially in the late dry season, because the supplemental feeds are often limited to small amounts of minerals, cereal by-products and protein meals (Powell et al. 1996) and these are mainly used for fattening animals (mostly sheep) prior to religious and social festivals, and lactating cows. The major constraint to supplementation is cost, as supplements are often expensive for livestock keepers considering their poor financial base. Although supplementation is beneficial from animal production point of view; for crop production, the benefits in terms of crop yield from using the supplemented animals in manuring crop fields is a decisive factor in opting for night corralling with supplementation instead of night grazing. Also, the economic consideration in terms of net returns from additional weight gain (meat produced), milk production and work output (in case of oxen) by the animals through night grazing compared with net returns from increased crop yields through manuring resulting from night corralling is an important factor in identifying feasible management practice(s) that take(s) care of the animals' needs as well as the need for soil fertility improvement. Even if the latter is more economically attractive, mixed crop-livestock systems cannot rely solely on manure to improve soil productivity because it cannot replenish annual nutrient harvests from cropland (Powell et al. 1996). Therefore, sustainable increase in agricultural production in the West African Sahel requires not only an optimal use of manure, but also external inputs such as fertilizers (van Keulen and Breman 1990).

2.4 Conclusion

Results from grazing trials showed that animals that had additional grazing time in the night consistently had higher forage intake and consequently, higher average daily gain than those that grazed only during the day in all seasons. However, additional grazing at night reduced the amount of manure that could be collected for crop fields when compared to animals that are corralled at night. When animals are supplemented, night grazing appears less relevant as the length of night grazing time did not significantly affect average daily gain in the critical late dry season. Although supplementation is beneficial from animal production point of view; for crop production, the benefits in terms of crop yield from using the supplemented animals in manuring crop fields is a decisive factor in opting for night corralling with supplementation instead of night grazing.

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Chapter 3
Managing Fertilizer Recommendations in Rice-Based Cropping Systems Challenges and Strategic Approaches

Vincent Boubie Bado, Koffi Djaman, and Mel Cesse Valère

Abstract Improving agricultural productivity to facing the fast growing food demands is the huge challenge of Sub-Saharan Africa (SSA). Fertilizer is a powerful productivity-enhancing input, but farmers of SSA use only 5 to 9 kg ha^{-1} of fertilizer, ten time less than Latin America and Asia (50 and 80 kg ha^{-1}, respectively). Rice (*Oryza sativa*) is one of the most important food crops of SSA and rice consumption is growing faster than the consumption of any other commodity in Africa. Rice-based systems have high potential for improving food production through an efficient management of fertilizers. The biophysical environment, cropping systems and, socio-economic environment of farmers including market opportunities are the main factors for development of appropriate fertilizer recommendations. This paper makes a critical review of rice-based systems in Africa and the main achievements on fertilizer recommendation, and further identifies the main challenges and opportunities to improve fertilizer use efficiency in rice-based systems. The opportunities offered by the new concepts, modeling and decision support tools that have been recently developed for better management of fertilizers in rice systems have been discussed. Beyond the traditional techniques of blanket fertilizer recommendations by country, some suggestions are proposed to improve the utilization of the new concepts and decisions support tools for better management of fertilizer in the rice-based systems.

Keywords Nutrient management • Rice cropping system • Fertilizer recommendation • Management tools

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Contents

3.1 Introduction

To meet the fast growing food demands, Sub-Saharan Africa (SSA) countries have to improve agricultural productivity. Fertilizer is a powerful productivity-enhancing input, but SSA uses very little quantities of fertilizers compared to the rest of the word. From 1970 to 2000, SSA applied 5 to 9 kg ha-1 of fertilizer, constricting with the 50 and 80 kg. ha^{-1} of fertilizer applied in Latin America and Asia, respectively (Yanggen et al. 1998).

Rice (*Oryza sativa*) is one of the most important food crop of the developing world and the staple food of more than half of the world's population. Rice consumption is growing faster than the consumption of any other commodity in Africa. From 1961 to 2006, rice production grew at 3.23% while the consumption increased by 4.52% (Diagne et al. 2012; Seck et al. 2012), indicating the widening gap between supply and demand. Rice is the leading source of food energy in West Africa and all member countries of the Economic Community of West African States (ECOWAS) are net rice importers (Seck et al. 2010; Fiamohe et al. 2012). Regarding the importance and opportunities for rice production in Africa, many initiatives have been developed involving many stakeholders. A Coalition for Africa Rice Development (CARD), an initiative with an overall strategy and a framework for action, jointly proposed by the Alliance for a Green Revolution in Africa (AGRA) and the Japan International Cooperation Agency (JICA) has been developed to respond to the increasing demand for rice. Sub regional institutions and international frameworks of stakeholders are implemented to assist self-effort of African countries to increase the local rice production, building on the existing structures, policies and programs, such as the Africa Rice Center (AfricaRice); the Comprehensive Africa Agriculture Development Program (CAADP) and the Africa Rice Initiative (ARI).

Many countries are investing a lot of efforts and resources in the rice sector, particularly after the Rice food crisis of 2008. However, the low productivity due to the high cost of inputs such as fertilizer remains a limiting factor to increase the global rice production in Africa. For example, while the simulated potential yield of irrigated rice with new improved varieties is 8–12 tons ha^{-1} in West Africa Sahel (WAS) (Dingkuhn and Sow 1997), the average yields in farmers' fields vary from 4 to 6 tons ha^{-1} (Haefele et al. 2002; Kebbeh and Miezan 2003).

Yanggen et al. (1998) calculated that the ratio of kilograms of output per kilograms of input for rice in SSA ranged from 7–20 with an average of 12, which is higher than the rule-of-thumb threshold of 10 and close to the average of 11.4 for Asian and Latin American. The yield for unfertilized rice in SSA was roughly the same as Asian and Latin America, showing that rice had more favorable ratio than maize in Africa. This better land productivity with rice is probably explained by the fact that most of the rice is irrigated or cultivated in lowland environment with less water stress. Working on economical analysis of factors of productivity in Senegal, Diagne et al. (2012) pointed out that fertilizers are robustly found to be the single most important source of productivity and technical efficiency levels of irrigated rice.

Rice is grown in West Africa in a wide range of agro-ecological zones from the humid forest to desert areas. Within these regional agro-ecological zones, five main systems of rice cultivation are distinguished with respect to water supply, soil hydrology and topography (Windmeijer et al. 1994). Irrigated rice systems mostly are cultivated in deltas and flood plains with good water control. The lowland rainfed rice systems are mostly cultivated in valley bottoms and flood plains with varying degrees of water control. The rainfed upland rice systems are cultivated on upland and slopes on aerobic soils. The deep-water and mangrove systems are present along riverbeds and in tidal areas in lagoons, deltas and in coastal areas, rarely having water control on anaerobic soils for most of the season.

Compared to traditional cereals (millet, sorghum, maize) rice has the highest yield potential. Improving the availability, fertilizer recommendations could highly contribute to food security while reducing rice importation in Africa. There is scope for sustainable intensification of the existing cropping rice-based systems through an efficient management of nutrients both from soil and fertilizers. In line with the efforts by African governments, under the Abuja Convention, to increase mineral fertilizer use to 50 kg of nutrients per hectare by 2015 and based on its potential productivity as well as its regional and international market opportunities, ECOWAS has identified rice as one of its priority crops. But rice is one of the cereal crops, which is widely cultivated in diversified environments and ecologies. For example, lowland rice is cultivated in heavy soils under periodical submersion that affect the dynamic of soil organic carbon, soil nutrients and fertilizer use efficiency. In contrast, upland rice is cultivated on upland soils, which are generally of lower quality compared to lowland soils. The main constraints of upland soils are the low contents of clay, organic carbon, exchange capacity (EC) and nutrients availability. Between the lowland and upland ecologies and depending on water management system and cropping systems, rice is cultivated in a diversity of biophysical environments that affect the nutrient use efficiency and the productivity of rice-based systems. While Nitrogen (N) deficiency is the main limiting factor of yield for lowland irrigated rice (Wopereis et al. 1999; Haefele et al. 2002; Bado et al. 2008), P deficiency, particularly in the low acidic soils is the main limiting factor for upland rice. Any fertilizer recommendation should take into account the biophysical environment, the cropping system and also the socio-economic environment of farmers including market opportunities. This paper aims to make a review of rice-based systems in West Africa and the main achievements on fertilizer recommendation to improve fertilizer use and rice productivity. Rice ecologies are used as the basis for discussion on strategic management of fertilizer management for rice-based systems. Based on the main achievements and weakness, the challenges and opportunities to improve fertilizer use efficiency in rice-based systems are discussed. The goal is to suggest alternatives for better management of fertilizers to improve nutrient use efficiency and productivity of rice-based systems in different ecologies.

3.2 The Rice Based Systems and Soil Constraints

Rice is both a staple and cash crop. Rice is a strategic commodity in the international and regional market. Because of the fast growing demand for rice, many efforts and initiatives have been invested to increase rice production, particularly after the food crisis of 2008 (Diagne et al. 2012; Seck et al. 2012). As for many crops, mineral fertilizer is one of the main factors of productivity and profitability. However, the use of fertilizer is limited by many factors. The most important factors that limit the use of fertilizers are the cost, affordability and the profitability. The development of fertilizer recommendation is generally based on the use of response curves to different nutrients (N, P, K) and calculation of the dose of fertilizer nutrients to apply for a target yield. Then, fertilizer recommendations are based on the optimum yields calculated from different requirements of nutrients. But in most countries of West Africa, current fertilizer recommendations are out of date, too general (“blanket recommendations”). The rice-based systems have three main ecologies in West Africa: lowland irrigated, rainfed lowlands and, rainfed upland. Each rice-based system has specific biophysical, agronomic and socio-economic constraints that limit crop productivities. Moreover, the demand for fertilizer and the application of fertilizer recommendations by farmers vary with the rice ecologies (rainfed or irrigated). Water availability, the capacity of farmers to pay for fertilizers, to manage water and weeds, determine their decision and quantity of fertilizer they may apply. For example, the irrigated rice systems are the most intensive systems. While mineral fertilizers are systematically used in the intensive irrigated lowland rice-based systems, the use of mineral fertilizers in the rainfed lowland or upland systems is limited.

3.2.1 The Rainfed Upland Rice System

Upland rice production is mostly subsistence-oriented farm households with limited use of external inputs mainly. Upland rice is grown as a sole crop or mixed with other crops such as maize and beans both in slash-and-burn systems and in intensified systems, where upland rice is rotated with other crops on permanently cultivated lands. Under this rice growing system, the land is tilled before the rainy season arrives, and the rice seed is normally broadcasted. While the upland rice area is relatively small (9.2%) in Asia, it coverts 44% of the total rice cultivated in Western and Central Africa, mainly in coastal areas in the humid and sub-humid agro-ecological zone (Defoer et al. 2002; Seck et al. 2010). Because of erratic rainfall patterns, poor weed control, low fertilizer use, and high disease incidence, yields normally remain low, normally averaging about 1 ton ha^{-1}. Weed competition is the most important yield-reducing factor (Johnson 1997) followed by drought, blast, soil acidity and general soil infertility. Farmers traditionally manage these stresses through long periods of bush fallow. However, population growth has forced farmers to reduce the fallow periods and concentrate their farming activities towards the fragile upper parts of the upland slopes. The slash and burn method of land clearing has aggravated the weed pressure and also led to a decline in soil fertility (Oldeman and Hakkeling 1990). Farmers also face high risk of crop failure and generally lower productivity levels. The main factors that limit rice yields under rainfed conditions are frequent drought in lack of water control and the original poverty of soils.

The upland rice production systems accounts for almost one-half of the rice area and contributes in West Africa to 29% of total rice production. Upland rice is cultivated on poor soils, which are generally acidic, fragile and prone to degradation, nutrient depletion. The low productivity of the upland rice based system is partly due to the limited use of nutrient inputs by small poor farmers with limited resources to invest in agricultural inputs such as fertilizers (Buresh et al. 1997; Becker and Johnson 1999; Oikeh et al. 2010). Even though these production systems have the potential for 2–4 tons ha^{-1}, rice yields are seldom above 1 ton ha^{-1} in most smallholder farmers' fields because of constraints such as soil acidification, inherently low soil fertility, and limited use of fertilizers (Oikeh et al. 2010). Most upland rice-based systems under shortened fallow management are characterized by inherently acid, P-deficient and low organic matter contents. Appropriate management option is to develop low external input systems that sustainably increases soil fertility as the use of appropriate varieties (acid-tolerant, P-efficient), enhanced soil organic matter N-balance through integration of N2-fixing legume, crop residue management and use phosphate rock alone or in combination with organic amendments.

3.2.2 The Rainfed Lowland System

Rainfed lowland rice is grown in bounded fields that are flooded with rainwater for at least part of the cropping season. About 40–45 million ha of rainfed lowlands supply about 20% of the world's rice production (IRRI, AfricaRice, CIAT 2010). The rainfed lowlands constitute 26% of the total rice area in Asia (Swain et al. 2005). This ecosystem accounts for a substantial rice area in Thailand (72.2%), Nepal (60.6%), Myanmar (Burma, 52.8%) and Bangladesh (43.1%). The rice yields under such ecologies in Asia are relatively low. In West and Central Africa, the rainfed lowland systems (flood plains and valley bottoms) constitute 31% of the total rice area (Defoer et al. 2002). Inland valleys constitute over 38% of the total wetlands in the sub-Saharan Africa and are cropped extensively with rainfed lowland rice in the wet season (WARDA 2008). In West Africa, this ecosystem forms significant rice growing areas in Senegal (47%), Burkina Faso (65%) and The Gambia (64%) (Seck et al. 2010). After the rains, water accumulates on the soil surface in lowland bounded rice fields. Rainfed lowland rice is grown on level to slightly sloping, unbounded or bounded fields, which are flooded by rains and groundwater for part of the rice-growing season, although in some seasons fields may not be flooded due to lack of rainfall. Rainfed lowland rice is also grown in flash-flood areas, where water level is suddenly increased during the rice growing season, causing short-term submergence. On-farm yield level is generally low due to various biophysical constraints and poor crop management practices (Becker and Johnson 2001b; Touré et al. 2009). Furthermore, in inland valleys, natural resources (particularly water and soil resources) are strongly correlated with their position in the toposequence (Homma et al. 2003; Haefele et al. 2006; Tsubo et al. 2006;). Thus, better understanding of the yield determining factors in rainfed lowland rice cropping is prerequisite for developing good agricultural practices. Most lowland fields in West Africa have no water control such as bunds or drainage system while bunds could improve productivity by 30–100% of yield increase (Raes et al. 2007; Worou 2012). For example, applied nitrogen efficiency of rainfed lowland rice is improved by the bund with gain due of 10–12 kg grain kg in Cote d'Ivoire (Becker and Johnson 2001a; Asubonteng 2001; Touré et al. 2009). In combined analysis over four seasons in Benin, Worou (2012) demonstrated that only bounding increased rice yield by 29% and fertilizer application increased rice yield by 28% without interaction between the two factors. Rainfed lowlands in inland valleys present a high potential for rice production in West Africa. However, rice yield in the lowlands is, in general, low due to various constraints such as poor soil fertility, drought, iron (Fe) toxicity, and poor crop management practices (Worou 2012).

Many studies indicated that the application of P, K and Zn in conjunction with N in lowlands is an effective way of reducing iron toxicity in rice (Yamauchi 1989; Yoshida 1981; Worou 2012). In a study that assessed the spatial and temporal variability in growth and yield of lowland rice cropping in an inland valley with two crop management options (bounding and fertilizer application), Worou (2012) concluded that bounding improved rice yield up to 1 ton ha^{-1} and interactions of season- by-position in the toposequence and season-by-fertilizer application on rice yield were associated with Fe toxicity and climatic conditions.

Furthermore, iron (Fe) toxicity in the soil is considered as one of the major constraints to rice production in rainfed lowlands in West Africa (Becker and Asch 2005). The reductive conditions found in lowland soils are a prerequisite for the development of iron toxicity through the solubilization of virtually all iron compounds in the soil into its ferrous form (Fe2+). Two levels of toxicity can be observed in the wetland system: the primary iron toxicity explained by an apparent sensitivity of rice seedlings to high amounts of Fe2+ accumulated just after flooding, and the secondary iron toxicity described by the excessive Fe2+ uptake caused by an increased root permeability and enhanced microbial iron reduction in the rhizosphere (intensive exudation) during the physiologically active phase of rice plant between heading and flowering (Prade et al. 1986). Fe toxicity can be also linked to nutritional imbalances due to low availability of P, K, Zn, Ca or Mg rather than to a high content of soluble iron in the soil solution. Therefore, iron concentration in the leaf tissue is a much better indicator for the occurrence of iron toxicity than extractable iron in collected soil samples.

High iron concentrations in soil can reduce the uptake of other minerals such as nitrogen (N) and phosphorus (P) by rice plants (Yoshida 1981; Diatta and Sahrawat 2005), and consequently reduce rice yield (Chérif et al. 2009). Increased ponded water level due to development of bunds to avoid water stress may increase risk for Fe toxicity, resulting in reduced rice yield or fertilizer use efficiency. However, little is known about the effects of bounding and fertilizer application on rice yield in the areas where Fe toxicity is one of major constraints. Therefore, the objectives of this study were to quantify the effects of toposequential position, bounding and fertilizer application and their interactions on growth and yield of rainfed lowland rice in an inland valley in North-West Benin, and to examine if year-to-year variation in climate condition impacted the results.

3.2.3 The Irrigated Rice System

In West and Central Africa, only 12% to 14% (0.5 million ha) of the total rice area is irrigated (Somado et al. 2008). This includes 80% of the rice area in Cameroon (14,700 ha), 55% in Niger (14,000 ha), 30% in Mali (52,920 ha) and 20% in Burkina Faso (6750 ha). Irrigated rice in these countries (except Cameroon) is mainly in the Sudan Savanna and Sahel, which account for nearly 60% of the irrigated rice area in West and Central Africa. Irrigation systems include dam-based irrigation, water diversion from rivers and pump irrigation from surface water or tube-wells (Defoer et al. 2002). On average, yields from farmers' irrigated rice fields in the Sahel are around 5 to 6 tons ha^{-1} per season, with potential yields varying from 8 to 11 tha^{-1} per season (Haefele et al. 2000). The very high yield potential in the Sahel is due to high solar radiation levels and relatively favorable temperatures. African rice gall midge, rice yellow mottle virus and blast are the major pests found in the irrigated rice ecosystems in Africa (Somado et al. 2008).

Water is an available resource in irrigated rice schemes. The availability of water in irrigated lowland rice system induces some agronomic problems such as weed pressure and nitrogen losses (denitrification, volatilazation) more than in the rainfed lowlands system,. High yielding varieties are cultivated with appropriate high doses of fertilizers coupled with improved management techniques. During the raining season, farmers do not always have full water control. Hence the boundaries between lowland and irrigated systems are not rigid. Water control may change over time and space. The level of water control dictates in broad terms the production potential of a system and knowledge on the dynamics of water control is therefore extremely important. Nutrient recoveries (in particular N use efficiency) are affected by water management. Despite its high yield potential 'blanket recommendations' of mineral fertilizers are widely used without taking account the new improved varieties, soil type, cropping system, the growing season and water management. These lead to poor inputs use returns, increasing production cost and decreasing competitiveness of irrigated rice. The productivity and profitability of irrigated rice-based systems can be improved by an integrated development and management of technologies adapted to the production environment of small-scale farmers (Kebbeh and Miezan 2003). This objective could be achieved by a systems approach helping decision makers and farmers to adopt dynamic choices according to environment opportunities rather than the traditional research (Jones et al. 1998). In addition to these three main ecosystems, mangrove1 rice growing systems also form an important part of the rice production systems in some countries.

3.2.4 Soil Constraints

As a consequence of biophysical factors and water regimes, rice is cultivated on a diversity of soils. The dynamic of nutrients from soil and fertilizers is differently affected by the management practices of water during the cropping seasons. Using the Fertility Capability Soil Classification (FCC) system (Sanchez and Buol 1985; Sanchez et al. 2003), Haefele et al. (2014) identified four groups of soils. The first two groups ('good' and 'poor' soils) do not have major soil chemical constraints, but differ in their degree of weathering and, therefore, their indigenous soil fertility. The third group ('very poor' soils) represents highly weathered soils with very low nutrient availability and a high probability of soil chemical constraints to crop growth (acid, low nutrient reserves, low CEC, Al toxicity, high P fixation). The last group combines the most frequently cited 'problem soils', i.e. acid-sulfate soils, peat soils, saline and alkaline soils, which are characterized by specific and severe soil chemical constraints. The majority of rice soils are very poor (37%), followed by equal fractions of poor (28%) and good soils (27%). Overall, problem soils are not common and make up 'only' 8% of all rice soils in Africa

3.3 Fertilizers Recommendation for Rice Systems

The doses of fertilizer recommendations, type and nutrients applied of different countries of West Africa are summarized on Table 3.1.

The main observation is the high variability of recommendations even for the same ecology. For example, N fertilizer recommendations vary from 90 to 130 kg ha^{-1} in Burkina for the same ecology of irrigated rice cultivated under full water control conditions. As showed by Bado et al. (2011), some explanations of this

Table 3.1 Fertilizer recommendations for rice in some countries in Africa

Country	Rice ecology	Doses of nutrient applied (kg ha-1)	References
Nigeria	Lowland	60N-13P-25K	Ekeleme et al. (2008)
	Rainfed upland	50N-30P-30K	
Benin	Rainfed lowland	55N-18P-33K	Yabi (2013)
	Rainfed upland	78N-15P-27K	Worou (2012)
Togo	Lowland	122N-13P-25K	Meertens (2001)
	Rainfed upland	45N-10P-19K	Aboa et al. (2008)
Senegal	Irrigated lowland	120N-26P-50K	Haefele et al. (2013)
	Rainfed (upland/lowland)	100N-13P-25K	Lô (2010)
Mali	Irrigated lowland	133N-20P-40K	DNA (2012)
	Rainfed (upland/lowland)	60N-10P-10K	
Côte d'Ivoire	Irrigated lowland	71N-20P-38K	CNRA (2005)
	Rainfed upland	70N-21P-30K	Gala-Bi et al. (2011)
Burkina Faso	Lowland	82N-31P-30K	Segda et al. (2005)
	Rainfed upland	67N-16P-18K	Karboré (2011)
Ghana	Lowland	90N-26P-50K	Buri et al. (2012)
	Rainfed upland	90N-20P-30K	Nyalemegbe et al. (2012)
Tanzania	Lowland	40N-10P-0K	Nowo et al. (1993)
	Rainfed upland	–	
Sierra Leone	Lowland	60N-18P-34K	GOSL (2005)
	Upland	60N-18P-34K	
Egypt	Lowland	143N-16P-47K	Abd El-Hadi et al. (2013)
Malawi	Lowland	83N-11P-0K	Mutegi et al. (2015)
	Upland	83N-11P-0K	
Gambia	Lowland	70N-30P-30K	Ceesay (2011)
	Upland	70N-30P-30K	
Ethiopia	Lowland	69N-10P-0K	Tilahum et al. (2007)
	Upland	–	
Mauritania	Lowland	156N-20P-0K	Haefele et al. (2001)

variability in fertilizer recommendations may result from multiple interactions within soil type; yield potential of varieties, the cropping season, farmer's practices (such as weed control) and the type of fertilizer available to be used for calculation fertilizer recommendation (Fig. 3.1).

3.3.1 Irrigated and Rainfed Lowlands

In general, the recommended N rates for lowland rice usually range from 60 kg/ha to 120 kg/ha, applied in 2–3 splits at planting, early tillering and panicle initiation.

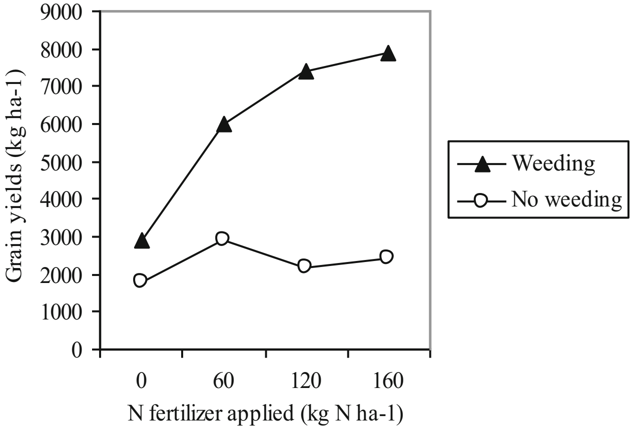

Fig. 3.1 Effects of weeds control (weeding and no weeding) on irrigated rice responses to N fertilizer applications in the Senegal River Valley (Bado et al. 2011)

An additional split at booting can be beneficial in very high-yielding systems (Wopereis-Pura et al. 2002), depending of yield potential of varieties and weed control. Good control of weeds is an important factor of fertilizer N use efficiency in irrigated and lowland systems. As showed by Fig. 3.1, good response to fertilizer applications are obtained with good control of weeds, while poor control of weeds leads to poor response to N applications (Bado et al. 2008) (Fig. 3.1). Many studies indicated that N fertilizer recommendations depended of the cropping. The optimum rate of N fertilizer vary from 90 to120 kg N/ha during the wet season (Haefele et al. 2002; Bado et al. 2010). Very high N rates up to 150 kg/ha can be recommended in irrigated rice system during the dry season, if high solar radiation enables potential grain yields of up to 12 t/ha (Haefele and Wopereis 2004). The critical limits of soil extractable P vary from 7 to 9 mg P ha^{-1} and from 15 to 17 P ha^{-1} with the P-Bray1 and Olsen method, respectively (Haefele et al. 2004; Bado et al. 2008) (Fig. 3.2). Below theses critical limit, the applications of 20–25 kg P fertilizer can maintain good level of P to ensure good yields.

Potassium fertilizers are to be applied along with N and P on poor soils, if higher yields are targeted, and especially if two (high-yielding) crops are grown per year regularly. The amount of K that needs to be applied also depends on K inputs from the irrigation water and from dust depositions. In West Africa, the dust deposition (dry deposition) is high at the northern fringes of the Sahel (e.g. in the Senegal River valley and in the Office du Niger, Mali) and decreases towards the south (Haefele et al. 2004, 2013).

On two long-term fertility experiments implemented by AfricaRice in the Senegal River Valley, Bado et al. (2010) showed that soil organic carbon was always maintained or increased irrespective of fertilizer application and rice yields

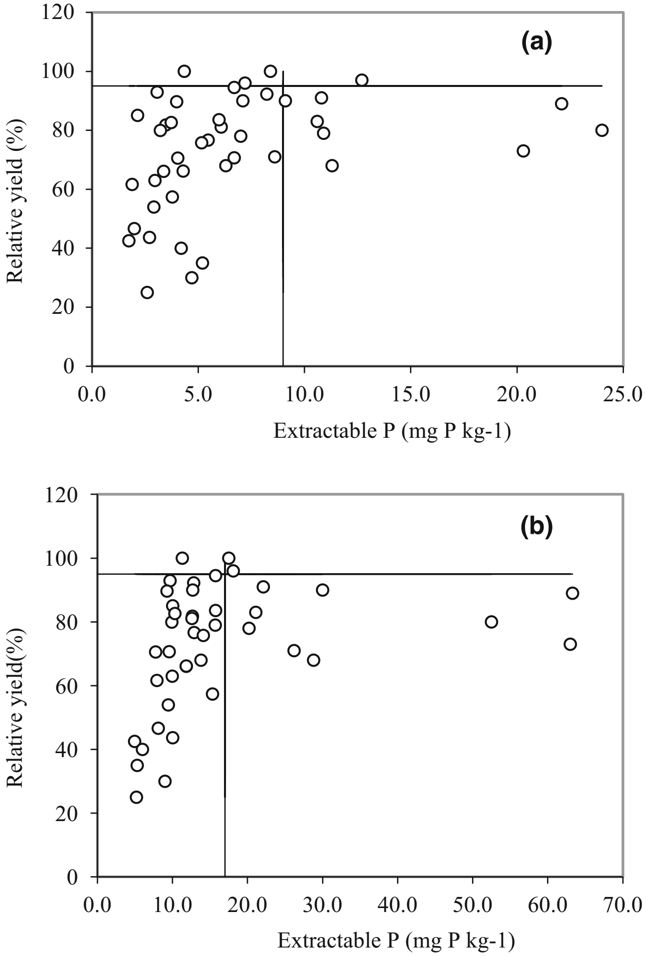

Fig. 3.2 Relationships between soil extractable P and yields and critical limit of soil P of a Gleysol under irrigated rice in the Senegal River Valley, as determined by the Cate and Nelson graphical method with (**a**) the Bray1 extractant (9 mg P kg-1 of soil) and (**b**) the Olsen extractant (17 mg P kg-1 of soil) (Source: Bado et al. 2008)

declined only when rice was cultivated without NPK fertilizer or when only N-fertilizer was used (Fig. 3.3). They suggested to looking for alternatives for better management of fertilizers to improve irrigated rice productivity and profitability. While N should be applied each season, it is probably not necessary to apply P and K each season. For example, seasonal applications of N (each cropping season) and annual applications (one season per year) of P and K can be an option to improve fertilizer management, rice production and profitability.

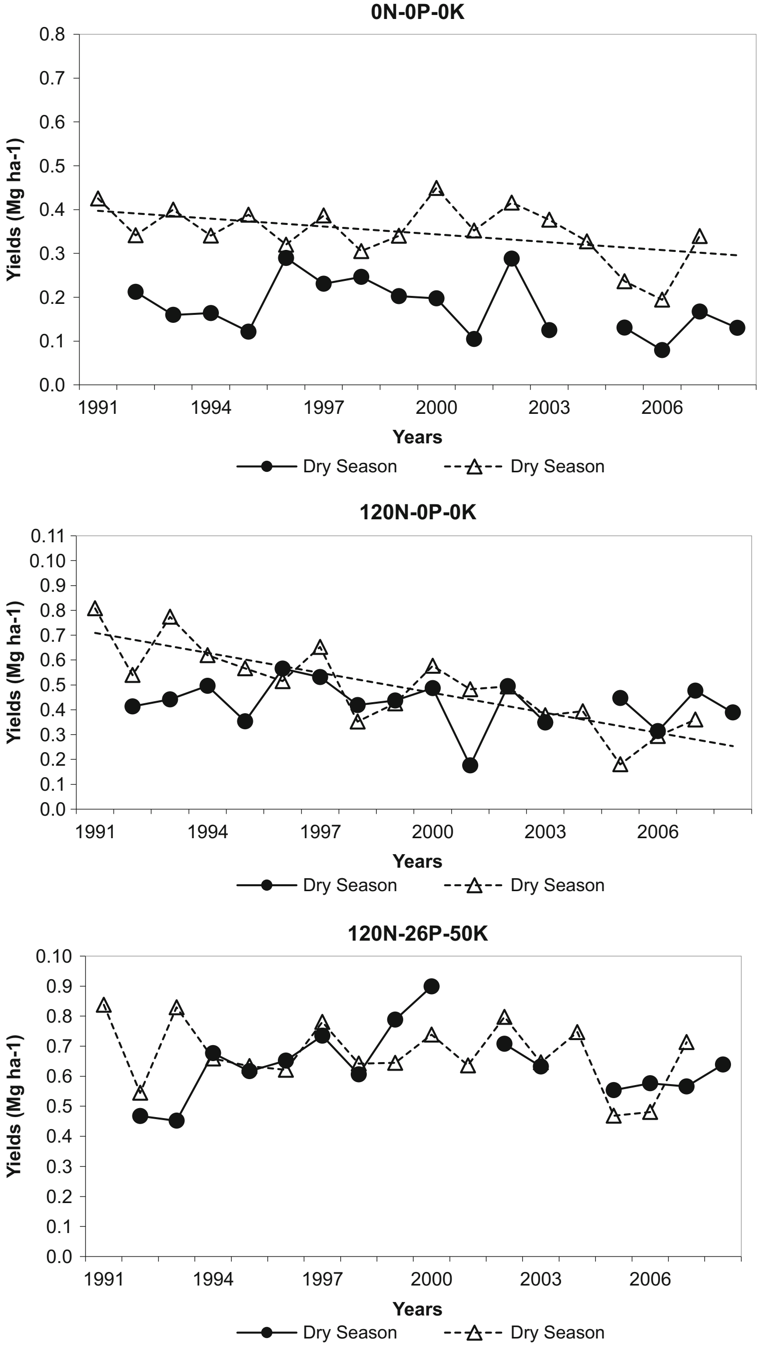

Fig. 3.3 Influence of fertilizer applications on rice grain yields at Fanaye in the Senegal River Valley during 18 years (1991–2008) during the hot dry season (HDS) and wet season (WS). The lines of yield trends indicated that the significant linear relationship ($p < 0.05$) existed between yields and year (Source: Adapted from Bado et al. 2010)

3.3.2 *Rainfed Upland*

In contrast with lowlands, phosphorous deficiency and high P-fixing capacity associated with low organic carbon and low availability of nitrogen are the main limiting factors in upland soils (Becker and Johnson 2001b; Sahrawat et al. 2003). Because of water constraints and frequent droughts, fertilizer application is more effective in high-rainfall conditions. In general, the recommended N rates for upland rice usually range from 50 kg/ha to 80 kg/ha, applied in 2–3 splits at planting, early tillering and panicle initiation. The critical limit of soil extractable P for upland rice ranges from 14 to 16 mg P ha^{-1} (Sahrawat et al. 1997; Sahrawat et al. 2001, Bado et al. 2010) and P fertilizer applications vary from 13–25 kg P ha^{-1}. Potassium is less limiting. Around 10–20 kg K ha^{-1} are usually applied.

Because of the original poverty of upland soil (low OC, clay content, acidity and high P-fixing) and the limited resources of small farmers to afford mineral fertilizer, organic inputs are an important productivity factor of upland rice. Promising alternative cropping systems include the use of weed-suppressing and multi-purpose legumes as short-term fallow crops (Becker and Johnson 1998, 1999; Akanvou et al. 2000; Saito et al. 2010). Intercropping upland rice with grain legumes like cowpea or soybean, rice–grain legume rotations or integrating early maturing legumes as pre- or post-rice crops improve the productivity of upland rice systems (Oikeh et al. 2008).

Fertilizer recommendations (Table 3.1) show the difficulty to calculate accurate doses of nutrient. Fertilizers communally available on local market are not always adapted for rice. For example, many formula of the complex NPK fertilizer available in many countries are formulated for the most important industrial crops such as cocoa (Côte d'Ivoire) or cotton (Burkina). Fertilizer recommendations for rice are generally adjusted using urea and the available NPK fertilizers. For example, excessive doses of P are recommended on lowland rice in Burkina because of the difficulty to balance N, P and K nutrients with urea (46% N) and NPK fertilizer (14-23-14).

3.4 New Concepts and Tools for Management of Fertilizers in Rice Systems

Rice is becoming a strategic cash crop, particularly for farmers as source of food and incomes in West Africa countries, which aim at reduce rice importations. The objective of self-sufficiency in rice is become the political slogan of most of the ECOWAS countries. Improving fertilizer use efficiency through appropriate fertilizer recommendations would contribute to increasing the productivity, profitability and competitiveness of local rice production, a huge option to reach rice self-sufficiency. Specific approaches and decisions supports tools have been developed for better management of fertilizers in rice systems. The new approaches of fertilizer recommendations aim to achieve more efficiency in the use of fertilizer, increase productivity with more profit to farmers, result in higher yields per unit of applied fertilizer, and protect the environment by preventing excessive use of fertilizer.

3.4.1 The Challenges

The technical and environmental challenges to be considered are related to the high diversity of rice ecologies and rice based cropping systems. The diversity of soils, water regimes, frequent droughts due to variable rainfall (Balasubramenian et al. 2007), cropping systems and management practices are to be considered in the development of fertilizer recommendations for rice. On the uplands, weak buffering capacity of soils due to low soil organic carbon (SOC) and clay content, low cation exchange capacity (CEC) and P deficiency are the main limiting factors to agricultural productivity of any crop including upland rice. Data from many long-term experiments in upland soils usually show yield declines over time as a consequence of a decrease in soil organic carbon (SOC), soil acidification and a decrease of nutrient use efficiency (Bationo and Mokwunye 1991; Bado et al. 1997; Bationo et al. 2008). The socio economic realities of small and poor farmers with limited resources to buy fertilizers are to be considered. The most serious abiotic constraints should be included.

In contrast to the poor upland soils, lowland soils of the inland valleys have generally higher organic carbon and clay contents, a better CEC and water retention capacity, offering better conditions for crop production (Bado et al. 2010). The wetlands of Sub-Saharan Africa are affected by Fe, Al and Mn toxicity in the wet forest zones and in waterlogged soils (Buddenhagen 1986; Sahrawat 2004). Moreover, permanent water logging and rice monoculture have caused microelement deficiencies, especially zinc and sulphur. Zinc deficiency is normally observed in soils with one or more of the following characteristics: high pH, high organic matter content, high availability of P or Si, high Mg/Ca ratio and low available Zn (Ponnamperuma and Deturck 1993). The traditional rainfed lowlands are also complexes. Soils have better properties and water is more available compared to upland environment. But one of the main constraints comes from the non-control or poor control of irrigation systems, leading to others problems: losses of nutrients (particularly N), pest, weed pressure, sometimes Fe^{2+} toxicity. Because of those problems, rainfed lowlands are under-utilized. Farmers use many cropping systems in the upland rice-based system,. Crop diversification can help for a better exploitation of the high production potential of lowlands. Modeling approach, focus on integrated management of multi cropping; water regime and inputs (fertilizer, herbicides) could help to identify appropriate management options.

Fertilizer requirements of irrigated rice are higher in the more intensive production systems. But the long-term and intensive cultivation of irrigated rice with periodical flooding affect the dynamics of SOC, soil pH, cation exchange capacity and nutrient use efficiency (Cassman et al. 1997). Some results from long-term experiments in Asia showed yield declines of 70 to more than 200 kg ha^{-1} with best management practices over a period of 10–24 years (Flinn and De Datta 1984; Cassman et al. 1995; Cassman et al. 1997). In West Africa, data of a long-term fertility experiment conducted by AfricaRice showed that soil organic carbon was maintained or even increased with the mono cropping of irrigated rice over 18 years or 36 cropping seasons (Haefele et al. 2004; Bado et al. 2010). The recycling of crop residues and roots in the flooded conditions of irrigated rice systems explained the status of SOC (Bado et al. 2010). The decomposition of plant residues is typically slower in submerged soil than in aerated soil (Powlson and Olk 2000; Regmi et al. 2002; Sahrawat 2004; Zhang and He 2004; Mirasol et al. 2008). Crop residues are continuously recycled in the soil twice a year as a source of carbon, which are incorporated into young soil organic matter fraction (Cassman et al. 1995; Olk et al. 1996; Witt et al. 2000). In general, most of the irrigated lowland valleys in the Sahel and Sudan savannah have considerable soil K reserves (Buri et al. 1999; Wopereis et al. 1999; Haefele et al. 2004). Probably because of the relatively high soil K status, the exchangeable K of the LTFE did not show any significant depletion with the recommended doses of NPK fertilizer as already noted by Haefele et al. (2004). However, the highest doses of N fertilizers (180 kg N ha^{-1} or more) can probably induce K depletion with long-term cropping. While the quick decline of SOC necessitates the needs for organic fertilizers, the maintenance or buildup of SOC is maintained or even increased in flooded conditions of irrigated rice (Bado et al. 2010), coupled with the improvement of soil chemical properties (Sahrawat 2004) and better use of nutrients both from soil and fertilizers. Bado et al. (2010) observed that rice yields could be maintained during 18 years with the seasonal applications of only chemical NPK fertilizers, probably because of the improvement of soil chemical fertility with flooding (Sahrawat 1998) and the maintenance of SOC and NPK nutrient. Thus, the standard or traditional approach for developing fertilizer recommendations based on the selection of a soil test, calibration of the test levels with crop response to added nutrients, and identification of response categories cannot give accurate recommendations in wetland ecologies of rice. Many studies showed that this traditional approach did not work properly in lowlands soils because of dynamic nutrients in the periodical waterlogging wetlands environment (Haefele et al. 2004).

The rice-based systems have certainly a higher productivity. There is a need for appropriate management of fertilizers in line with diversity and potential productivity of these systems. The standard or traditional approach for developing fertilizer recommendations based on the selection of a soil test, calibration of the test levels with crop response to added nutrients, and identification of response categories is less appropriate for the rice-based systems. In the traditional approach, fertilizer recommendations are formulated for specific crop regardless of the cropping systems or the management of other nutrient sources such as crop residues. Experiments are usually conducted at particular experimental site in time and space with one or a limited number of plant genotypes. This traditional agricultural research is time consuming and many experiments on diversified sites during many seasons are sometimes used to provide little information (Jones et al. 1998). The new challenge is to develop new management strategies of fertilizer that could integrate the complexes interactions within ecological, biophysical and socio economic factors of the rice-base systems.

3.4.2 New Concepts and Tools for Fertilizer Recommendations

Facing the specific and diversity of rice systems, many efforts have been invested by some institutions to improve the management of fertilizers in rice systems. Particularly the two institutions specialized on rice research; the International Rice Research Institute (IRRI) and AfricaRice (former WARDA) have developed different concepts and methods for better management of fertilizer in rice systems. Beyond the blanket recommendation, the main objective was to propose appropriate methods and tools that help developing specific doses of fertilizer for different ecologies of rice (uplands, lowlands), time of application, cropping season and system for better productivity and profitability. This approach leaded to the newest development of the new concept of site-specific nutrients management for rice.

3.4.3 The Site-Specific Nutrient Management in Rice System

The International Rice Research Institute (IRRI) has developed the concept of site-specific nutrient management (SSNM) in rice (Dobermann and White 1999; Witt et al. 1999; Dobermann et al. 2002; Saito et al. 2015). This approach relies on the scientific principles determined during 15 years of site-specific nutrient management (SSNM) research in Asia (Saito et al. 2015). The concept of SSNM) is the dynamic, field-specific management of nutrients in a particular cropping season to optimize the supply and demand of nutrients according to their differences in cycling through soil–plant systems (Dobermann and White 1999; Wang et al. 2001). Balanced fertilization increases nutrient use efficiency and profit to farmer, results in higher yields per unit of applied fertilizer and protects the environment by preventing excessive use of fertilizer.

A cloud-based decision-support tool named Nutrient Manager for Rice (NMR) was developed to deal with such specificity and provide farmers with field-specific nutrient management recommendations before the cropping season. The version is currently in the public domain is called Crop Manager; http://cropmanager.irri.org/) (Saito et al. 2015). NMR provides advice on when, how much, and what sort of fertilizer to apply. Agricultural extension officers or lead farmers can access NMR through a personal computer, smartphone, or tablet. The recommendations are calculated from farmers' replies to questions about the agro-ecological or administrative zone of their field, the variety of rice, availability of irrigation water, previous crop and management of its residue, previous rice yield levels, and fertilizer use (Saito et al. 2015). Fertilizer recommendations are developed in five steps: (i) Selecting an economic yield targeted based on the average yield of the past 3–5 crops (same season) attainable with farmers' current good crop management practices when nutrient-related constraints are overcome; (ii) Estimating soil nutrient supplies by using grain yield in nutrient omission plots (under favorable weather conditions and good growing conditions) as an indicator of the potential soil supply of N, P, and K in a cropping season; (iii) Calculating fertilizer N rates and use of plant need-based N management; (iv) Calculating fertilizer P2O5 rates and v) Calculating fertilizer K2O rates. More details are published in a practical guide (Fairhurst et al. 2007). SSNM technologies have been successfully evaluated in a wide range of farmers' fields in Asia and are now positioned for wider-scale validation and adaptation by farmers in Asia (Fairhurst et al. 2007).

Other decision supports tools are also used to develop SSMN recommendations. The most popular is the QUEFTS model (Quantitative Evaluation of Fertility of Tropical Soils). The QUEFTS model was initially developed to simulate interactions between N, P and K for tropical soils under maize crop (Janssen et al., 1990; Smaling and Janssen 1993; Janssen 1998; Witt et al. 1999). Information needed to estimate the total amount of N, P, and K to be applied included; climatic yield potential; yield goal; definition of the relationship between grain yield and nutrient uptake; recovery efficiencies of fertilizer N, P, and K; field-specific estimates of the indigenous N, P, and K supply; and potential constraints to fertilizer use. Some modified versions of QUEFTS have been performed later for different crops including rice (Haefele et al. 2004; Sattaria et al. 2014).

Haefele et al. (2003) developed a framework for improving fertilizer recommendations by combining the rice yield model ORYZAS (Dingkuhn and Sow 1997), a simplified version of QUEFTS called FERRIZ and field survey data to develop fertilizer recommendations. The dynamic ecophysiological ORYZA_S model provided potential rice yields under irrigation, based on weather conditions, cultivar choice and sowing date. This yield potential was then used in the static FERRIZ model, together with on-farm data on recovery efficiency of applied N, P and K, indigenous soil N, P and K supply. AfricaRice (former WARDA) has developed a decision tool called RIDEV, a dynamic model that simulates the optimal timing of the dates of sowing or transplanting, fertilizer application, weeding and harvest (Dingkuhn et al. 1995; Dingkuhn and Sow 1997; Haefele et al. 2003). This approach showed that (i) current uniform recommendations for the wet season performed well except on low-K soils where the application of K was profitable; and (ii) adjusting fertilizer doses to the lower yield potential in the dry season reduced costs and risk without reducing profit. Based on the analysis, the existing recommendation could be adjusted for the wet and dry seasons, keeping fertilizer costs and risk low, and having net benefits close to optimal.

Segda et al. (2005) used a combination of two simulation models and selected field data to develop alternative fertilizer recommendations for irrigated rice in the irrigation scheme of Bagré (Burkina Faso). RIDEV was used to improve timing of sowing and N fertilizer applications. FERRIZ was used to determine fertilizer recommendations, based on estimations of indigenous nutrient supply for N, P and K, yield potential, internal N, P and K efficiency of rice, fertilizer N, P and K recovery fractions, and fertilizer and rice prices. Simulations suggested decreasing P and K doses but increasing the N dose, leading to gross returns increase (Segda et al. 2010).

3.4.4 Rice Advice

Based on the experience in Asia, IRRI and AfricaRice have worked together to develop Nutrient Manager for Rice (NMR) starting with the Senegal River Valley (SRV) through the use of data on yields from previous fertilizer trials in irrigated lowland rice in West Africa for estimating indigenous N supply (e.g. Wopereis et al. 1999; Haefele and Wopereis 2004), potential yield and optimum sowing windows (Dingkuhn and Sow 1997), and expert knowledge on crop duration of popular varieties and crop management (Saito et al. 2015). A NMR for SRV has been developed with IRRI as an HTML5 application, which means it can be accessed through a web browser, using any of the major operating systems with equal effectiveness, from a smartphone or a personal computer (http://webapps.irri.org/nm/wa/). Saito et al. (2015) presented a pre-release version 1 of this tool called, Rice Advice. Evaluating the fertilizer recommendations provided by Nutrient Advice in terms of yield of irrigated lowland rice and profitability in comparison with farmers' fertilizer management practices (FFP) in the Senegal River valley, Saito et al. (2015) concluded that this new tool increases the yields and profitability in farmers' fields.

3.4.5 Integrated Crop Management

The rice cropping systems are more complex. More than availability of inputs (water, seeds or fertilizers), an appropriate management of inputs and crop calendars is one of the most important factors for an efficient use of resources and rice production and productivity. This is clearly observed for irrigated rice in the Sahel. In spite of good climatic conditions and availability of water on irrigated schemes, a good management of inputs remains essential to increase irrigated rice production and profitability. Based on this experience, AfricaRice has developed the concept of Integrated Crop Management (ICM) for rice. The concept of ICM recognizes that rice cultivation is a production system involving a wide range of components from land preparation to harvest and post-harvest management. These factors interact in an array of complex relationships and interdependencies that together determine crop growth, yield and profitability. Thus, rice productivity and profitability can be boosted by integrated technologies adapted to the production environment of small-scale farmers, combined with optimum management of fertilizers, weeds, varieties, seeds and cultural calendar (Wopereis et al. 1999; Haefele et al. 2000, 2002; Kebbeh and Miezan 2003;). A change in the management of one factor can affect the performance of other factors and/or crop growth, yield and profitability. The concept of ICM is a participative approach, focused on integrated management of resources and inputs of farmers for increasing efficiency and productivity of rice. It seeks to develop integrated technologies at the farm level (with the farmer as the ultimate integrator of management factors) that manages the cultivation of the crop as a total production system, taking into account all factors that impact crop growth, yield, quality and profitability. AfricaRice has particularly used the ICM concept to develop different management options of fertilizer (dose and time of application) for cropping calendar of irrigated rice.

3.4.6 Integrated Soil Fertility Management

Organic inputs are one of the main resources of nutrient inputs of small farmers, particularly on the upland soils. But large amounts of organic fertilizer (often not available) are required to maintain soil fertility levels. Organic input alone cannot ensure optimum productivity and sustainable maintenance of soil fertility. In opposite, the applications of inorganic fertilizers alone lead to yield gains in the short term but may lead to soil acidification and declining yields in the long term (Bado et al. 2010). The use of both inorganic and organic fertilizers, associated with high yielding germplasm better improve nutrient and water use efficiency leading to optimum productivity.

The concept of Integrated Soil Fertility Management (ISFM) is defined as a set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs and improved germplasm, combined with the knowledge of how to adapt these practices to local conditions, aimed at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity (Vanlauwe et al. 2010). All inputs need to be managed following sound agronomic principles. The goal is to optimize crop productivity through maximizing interactions that occur when farmers integrate fertilizers, organic inputs and improved germplasm, along with the required associated knowledge. The ISFM approach is more appropriate for rice in the rainfed (lowland and upland) system. Good productivity is particularly obtained by the upland rice-based system with the combined applications of mineral and organic fertilizer and crop rotation with nitrogen fixing legume crops.

3.5 The Way Forward

Good management of fertilizers cannot be achieved in the complex ecologies of rice systems with the traditional approach that delivers blanket recommendations without taking account the specific and diversified ecologies of rice. Only decision

Table 3.2 Concept, tools and methods to improve fertilizer recommendation rice-based systems.

Rice system	Concept	Tools	Institution
Lowland irrigated Rice	Site-specific nutrient management (SSNM)	Nutrient manger	AfricaRice
	Integrated crop management (ICM)	RIDEV	AfricaRice
Rainfed lowland	Site-specific nutrient management (SSNM)	Nutrient manger	AfricaRice
	Integrated soil fertility management (ISFM)	DSSAT, APSIM, IAT	IFDC
Rainfed upland	Site-specific nutrient management (SSNM)	Nutrient manger	AfricaRice
	Integrated soil fertility management (ISFM)	DSSAT, APSIM, IAT	IFDC

support tools using system approach should be use. Many progresses have been made in term of research and modeling tools. The Table 3.2 summarizes the available concepts, tools and methods that could be used in different systems of rice. The Nutrient Manager is the most appropriate to be used in the main three ecologies of rice in West Africa. In the more complexes systems of rainfed lowlands, the concept of ISFM should be used with modeling tools such as DSSAT, APSIM or IAT. The two regional institutions, AfricaRice and IFDC have the technical expertise to coordinate and promote the wide diffusion of the new decisions support tools in West Africa.

The challenge is to make these new tools available for use by scientists of National Agricultural Research Institutions, extension agents and farmers. This would be achieved through voluntary training efforts of the stakeholders. As a regional intuition in charge of coordination of research and development, CORAF/WECARD should play a role to mobilize resources and regional institutions (AfricaRice, IFDC) and regional expertise to develop and implement a strategy to facilitate the use of decision support tools for fertilizer recommendations.

3.6 Conclusions

Mineral fertilizers will continue to play a key role in boosting rice productivity given the current very low level of fertilizer use in Africa. Facing the high increase of the demand, rice is one the best opportunity to increase the use of fertilizer in Africa.

The most pressing challenge for rice-based systems is to promote the use of the new decision support tools to improve fertilizer use efficiency on an integrated nutrient management of nutrient for rice, rather than blanket fertilizer recommendations. There is a particular need to train a new generation of hands-on rice experts, through season-long training in rice management. AfricaRice has built a new training facility in Senegal for this purpose. There is a huge need to speed this dynamic to make rice a real business opportunity for Agricultural development in West Africa.

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Chapter 4
Soil Organic Carbon and Nitrogen in Agroforestry Systems in Sub-Saharan Africa: A Review

J. Bayala, A. Kalinganire, G.W. Sileshi, and J.E. Tondoh

Abstract Effective nutrient management is a key to sustainable agroforestry systems, chiefly in the current context of changing and variable climate along with increasing uncertainties of production systems to meet the needs for food security. The diversity of agroforestry systems throughout Sub-Saharan Africa results in a diverse nutrient management models with specific underlying mechanisms. Over the past decades several studies have been conducted on nutrient dynamics in agroforestry practices in various farming systems across a large range of agro-ecological conditions. We conducted a meta-analysis of the published data of four of these practices (alley cropping, improved fallow, mulching and parkland) for sub-Saharan region to examine their contribution to soil organic carbon and nitrogen content. The results of this analysis revealed an increase in both SOC and N contents of these practices over their corresponding treeless control plots. C to N ratios showed the higher values in the mulching and parkland practice as opposed to the alley cropping, which is nitrogen fixing species-based agroforestry technology. It has therefore been hypothesized that increase SOC may contribute to the provision of important supporting ecosystem services (nutrient inputs, the enhancement of internal flows, the decrease of nutrient losses, etc.). Therefore, agroforestry as a science hold promising solutions for alleviating soil fertility problems and achieving sustainable land management provided (1) resources sharing between components are better understood and (2) pathways for sustainable nutrient management are context-oriented and made available for users and policy makers.

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Keywords Agroforestry practices • Farming systems • Socio-ecological conditions • Validity domains • Up-scaling

Contents

4.1 Introduction

Human pressure on natural resources has led to their degradation with a drastic reduction in vegetation cover in Sub-Saharan Africa. The associated consequences of such pressure are decrease in soil organic carbon and increases in runoff and soil erosion that ultimately lead to reduced crop yields and increase human malnutrition in this region (Vågen et al. 2005; Moebius-Clune et al. 2011; Le et al. 2012). To revert the current trends, part of the solution lies in some forms of agricultural production that maintain a certain threshold of vegetation cover by integrating more trees on farmlands or in other words in some forms of agroforestry practices which are in general low external inputs technologies (Graves et al. 2004; Sileshi et al. 2008, 2010; Jerneck and Olsson 2013; Carsan et al. 2014). Agroforestry is basically defined as the inclusion of trees in farming systems and their management in rural landscapes to enhance productivity, profitability, diversity and ecosystem sustainability (ICRAF 2013).

Trees in farming systems play a range of ecological functions among which soil fertility improvement seems be the most accepted role, particularly through the increase in soil carbon and nitrogen (Bayala et al. 2014; Carsan et al. 2014). Through CO_2 fixation by photosynthesis and nitrogen by nitrogen-fixing, trees can increase soil fertility and by incorporating more biomass into soils enable more efficient use of inorganic fertilizers (Kater et al. 1992; Bationo et al. 2007). Indeed, it is known that CEC lower than 4–5 meq. per 100 g makes the use of fertilizer non economical (Kater et al. 1992). Soil fertility can also be improved through nutrient cycling where trees extract nutrients from the lower levels of the soil profile and return them to the surface through leaf litter and fine root decay (Bayala and Ouédraogo 2008; Nair and Nair 2014). All these processes will increase soil carbon content which is one of the key factors to consider when assessing the sustainability of cropping systems and their effect on the environment. This is particularly valid in Sub-Saharan, where kaolinite is the main type of clay in the soils (Andriulo et al. 1999; Bationo and Buerkert 2001; Bayala et al. 2006; Bationo et al. 2007). In many places of this region, Cation Exchange Capacity (CEC) strongly depends on the presence of organic carbon, which of course has an impact on soil fertility, and trees have been reported to have a significant impact on CEC (Kater et al. 1992). Thus, trees, and particularly agroforestry systems, are nowadays widely acknowledged as valuable land management options within various concepts including "climate smart" agriculture, ever-green agriculture, ecological or agro-ecological intensification (Garrity et al. 2010; Neufeldt et al. 2013; Tittonell and Giller 2013).

If trees have positive impact on soil fertility (C and N), such effects will depend on a number of factors including but not restricted to the tree species and their management, the ecological conditions, the soil and its management, etc. A number of practices have been deployed and tested with respect to soil fertility improvement. The present review aims at capitalizing the existing information about soil carbon and nitrogen improvement of four key agroforestry practices which are alley cropping, improved fallow, mulching and parkland.

4.2 Methods

4.2.1 Definitions of the Geographic Area and Practices Studied

This analysis focuses on sub-Saharan Africa covering an area from humid to semi-arid zones. The agroforestry practices were then grouped into the following four categories for the purpose of the meta-analysis: alley cropping, fallow, mulching and parkland.

1. Alley cropping: Alley cropping, a system in which food crops are grown between hedges of trees which are regularly cut back to minimise tree-crop competition for light, water and nutrients (Kang 1993; Tossah et al. 1999). In this practice, the application of tree prunings to the soil surface is reported to generate a number of benefits including the reduction external inputs, the improvement of mineral fertilizer use efficiency, the enhancement of biological activity, the recovery N supplied with the prunings in absence of crop growth (Vanlauwe et al. 1998). The woody component of this technology is generally a nitrogen species like *Acacia auriculiformis* A. Cunn. ex Benth., *Acacia mangium* Willd., *Acacia colei* Maslin & L.Thomson, *Acacia tumida* Benth., *Albizia lebbeck* (L.) Benth., *Gliricidia sepium* (Jacq.) Walp., *Leucaena leucocephala* (Lam.) de Wit, *Prosospis africana* (Guill. et Perr.) Taub., etc.
2. Fallow: Improved fallows consist of deliberately planted species – usually legumes – with the primary purpose of fixing N_2 as part of a crop-fallow rotation (Sanchez 1999). Improved fallows with herbaceous legumes are commonly called green manures or sometimes cover crops and are not included in the present review. Improved fallows with woody legumes are usually called by the tree used, for example '*Gliricidia* fallows' (Sanchez 1999).

3. Mulching: Mulching consists of covering the ground with a layer of plant materials in order to conserve soil water, to stimulate the activity of soil biota (e.g. termites) and to reclaim a degraded soil for crop production. This involves use of a range of plant materials (wild grass, crop residues or tree biomass, either leguminous or not) in the semi-arid area and sometimes in association with soil and water conservation techniques using crop residues or prunings from trees and shrubs or a mixture (Bayala et al. 2012).
4. Parklands: Parklands are anthropogenic vegetation assemblages derived from savannas ecosystems (Maranz 2009). Farmers usually protect naturally regenerating trees during tillage operations, keeping tree density low so that canopy cover is not continuous. Farmer managed natural regeneration (FMNR), which consists of selecting and thinning stems which sprout from indigenous tree and shrub stumps or appear as seedlings, has been actively used to obtain significant re-growth of trees on crop fields and fallow fields (Gijsbers et al. 1994; Reij et al. 2009). Therefore, parklands are a reflection of a slow process of species selection and density management of indigenous trees by farmers (Mortimore and Turner 2005). Key parkland species are *Acacia spp., Adansonia digitata* L.*, Borassus aethiopum* Mart.*, Faidherbia albida* (Del.) Chev.*, Ficus spp., Hyphaene thebaica* (L.) Mart.*, Lannea microcarpa* Engl. et K. Krause*, Parkia biglobosa* (Jacq.) R. Br. ex G. Don*, Pterocarpus erinaceus* Poir.*, Pterocarpus lucens* Guill. et Perr.*, Sclerocarya birrea* (A. Rich.) Hochst.*, Tamarindus indica* L.*, Vitellaria paradoxa* C. F Gaertn*, Ziziphus mauritiana* Lam., etc. (Bayala et al. 2012).

4.2.2 Data Collection

Data for the meta-analysis were compiled from publications and reports. The foci of the present analyses were carbon and nitrogen of the plot under the various agroforestry practises described above. The following criteria were used for a publication to be included in the analysis: (1) The data are from sub-Saharan Africa; (2) The publication contains reported carbon and nitrogen data of the four agroforestry practices and a corresponding control plot where the practice was not applied, with mean values reported numerically; (3) Data were from well designed and replicated experiments or observational studies either on a research station or on farmers' fields.

The studies included were located by searching through computer library databases (ICRAF, FAO, and Google Scholar). A search using the terms Agroforestry and soil fertility and any of the four practices and soil fertility yield a maximum of 1745 references. When restricted to sub-Saharan Africa 393 references where found. Finally, only 34 references fulfilled all the criteria listed above. These publications covered the semi-arid to humid agro-ecological zones (347 to 2500 mm) with the altitude of the study sites ranging from 200 to 1800 m and the rainfall from 347 to 2500 mm with both uni-modal and bi-modal rainfall patterns. In cases where the same data has been presented by the same author in two or more different publications, only one was included in this analysis. When data on more than one practice was available in the same publication or when data from different seasons and sites were reported, all were included. This yielded a total of 223 separate pairs of means (treatment and control) for carbon and 194 pairs of means for nitrogen. Some 62% of the studies came from on-farm trials and observational studies while 38% were from on-station experiments. Over 63% of study designs were laid out as randomized complete blocks, 27% as completely randomized designs and the rest 10% was split between Latina square and split plot designs.

4.2.3 Data Analysis

Data were converted to mean difference in soil carbon and nitrogen contents (D) which was defined as the difference in carbon or nitrogen between plot using a given agroforestry practice and the control of no such practice from the same study ($D = Me - Mc$). When both C and N data has been reported, C:N ratios were calculated and the difference between the treatment and control was also calculated using the same formula. Mean difference in carbon, nitrogen and C:N data were analysed by simple summary statistics. Data on D were further analysed using mixed models fitted using Restricted Maximum Likelihood (REML). Besides null hypothesis testing, statistical inference was based on the predicted means and their 95% confidence intervals (CI). One of the advantages of 95% CI over traditional hypothesis testing is the additional information they convey. The interpretation of the CIs is that if the same experiment was repeated many times, 95% of the time the D estimate would fall within the upper and lower confidence limits associated with the mean (Gelman et al. 1995). The upper and lower bounds of the CI give information on how big or small the true effect might plausibly be. Mean D for a given agroforestry practice treatment was considered different from 0 if the 95% CI did not include 0. If there is no difference between treatment and control the expected increase will be 0.0.

4.3 Results and Discussions

The results in Table 4.1 reveal that all of the technologies increase soil organic carbon (SOC) over the control. The 95% confidence intervals (lower upper) do not include 0. For example, alley cropping increased SOC by 20.57% (95 CI: 6.76–34.39), meaning the true value of SOC increase by treatment will fall between 6.76% and 34.39%; which is way above 0 (Table 4.1). Similarly to carbon, all of the technologies except improved fallows significantly increased nitrogen over the control. Improved fallows had variable response (Table 4.1). Negative values of the nitrogen difference in fallows may be due to the fact the species used do not fix

Table 4.1 Percentage increase in soil organic carbon (SOC) and nitrogen (N) due to various tree-based technologies over a corresponding tree less control for four agroforestry practices tested in Sub-Saharan Africa

Variable	Technology	Percentage increase	95% confidence intervals	
			Lower	Upper
SOC	Alley cropping	20.6	6.8	34.4
	Fallow	22.8	8.6	37.1
	Mulching	39.5	20.7	8.2
	Parkland	35.5	25.1	45.9
Nitrogen	Alley cropping	32.1	8.6	55.5
	Fallow	15.3	−12.1	42.7
	Mulching	32.4	4.8	60.0
	Parkland	35.5	17.2	53.8

nitrogen or the trees were still too young to displaying other processes of accumulating nitrogen which include deposit from animal (birds, livestock) and wind, the redistribution through the root systems, fine roots decay, litter decomposition, deep nitrate capture, etc. (Bayala and Ouédraogo 2008). The increases in both SOC and N revealed by the meta-analysis corroborate previous reports. Indeed, mature trees have always been associated with island of high fertility in the parkland systems in one hand (Bayala et al. 2006; Lufafa et al. 2008; Takimoto et al. 2009). On another hand, the three other practices studied (alley cropping, fallow, and mulching) are meant by nature to increase soil fertility particularly C and N (Kang 1993; Vanlauwe et al. 1998; Tossah et al. 1999). Indeed, the use of prunings and litter for soil fertility improvement is one of the earliest benefits claimed in agroforestry-based cropping systems especially in addressing soil N deficiency. However, the extent of soil improvement is related to the soil, the ecological conditions, the quality of the organic materials used because the nutrient content (especially N and P), lignin and polyphenol concentrations of litter strongly influence its rate of decomposition and nutrient release to the soil (Palm and Sanchez 1990). There is a general consensus that net N mineralisation occurs if the N concentration is above 2% and immobilisation occurs below that concentration (Palm and Sanchez 1990, 1991; Bayala et al. 2005). Fast release of N may be linked with high microbial activity inducing N deficit. Therefore, immobilization is likely to occur during the decomposing process of the leaves of some species and that may explained why in some cases the control N content was higher than that of the agroforestry practice (Bayala et al. 2005). Furthermore, if legume tree-based farming systems are able to increase soil nitrogen (N) availability and therefore improve soil fertility and crop yields sustainably, they can also induce the release of nitrous oxide (N_2O) in the surrounding environment. Such potential hazard should be taken into consideration (Rosenstock et al. 2014).

C:N ratios varied with technology with all of the technologies that increased the values of this parameter but alley cropping had significantly lower values compared to mulching and parklands (Table 4.2). Pruning is the main management tool in

Table 4.2 Percentage increase in C to N ratios in various tree-based technologies tested in Sub-Saharan Africa

Variable	Technology	C:N	95% confidence intervals	
			Lower	Upper
C:N ratio	Alley cropping	8.7	3.8	13.9
	Mulching	23.2	18.2	28.2
	Parkland	17.3	15.4	19.2

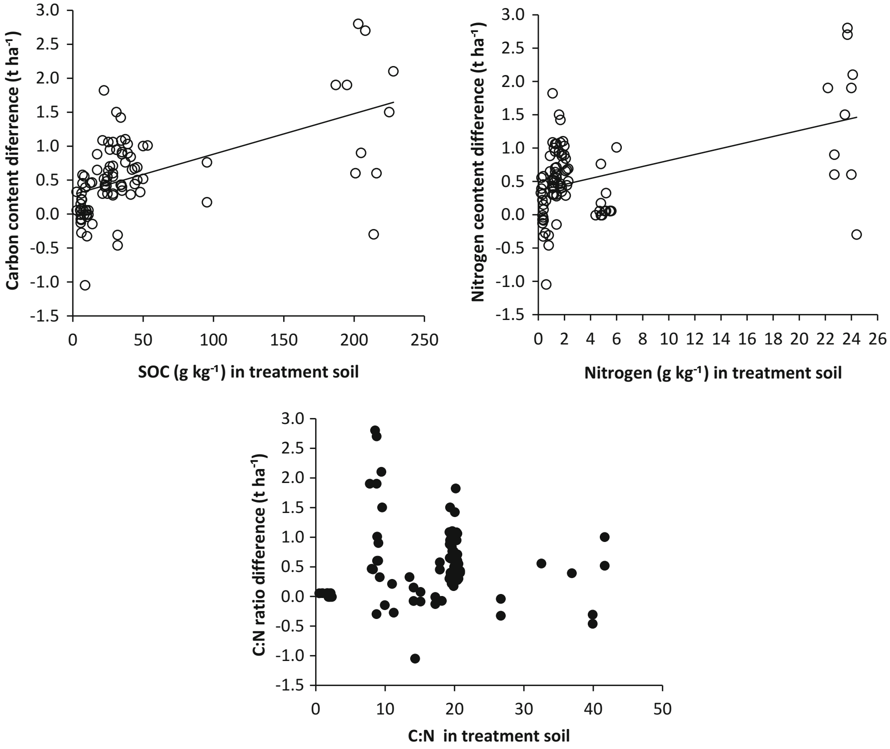

Fig. 4.1 Variation in carbon, nitrogen and C:N ratio differences with SOC, N and C:N in treatment plots for four agroforestry practices tested in Sub-Saharan Africa

alley cropping and this technique the potential to reduce the negative effects of trees in agroforestry parkland systems by reducing excessive shading and belowground competition through a reduction of fine root density (Jones et al. 1998; Bayala et al. 2008). Data points were too few for improved fallows. Therefore, fallows were not included in the analysis. The nutrient content difference (carbon and nitrogen) seems to increase with increase in nutrient content of the agroforestry plot whereas the opposite appears to be true for the C:N (Fig. 4.1). This indicates the difference that exists in the quality of the source organic matter of the studied practices. Lower C:N values in alley cropping practice is in line with the quality of the organic matter which is in principle from nitrogen fixing species. Indeed the organic matter using for mulching is generally a composite one with a mix prunings from trees that may be from leguminous species or not and crop residues. Conversely, litter from parkland species is also formed of leguminous and non-leguminous materials. In turn, by definition the species used in ally cropping are leguminous explaining the C:N is the lowest in this practice associated with higher mineralisation of the applied biomass (Palm and Sanchez 1990, 1991). All of the technologies increased the C:N ratio but alley cropping had significantly lowered values compared to mulching and parklands. As opposed to alley cropping, practices that result in high C:N may be associated with a decrease in decomposers population diversity in one hand (Wachendorf et al. 1997). On the another hand, higher SOC is associated with better soil physical properties improvement. As most of the soils in sub-Saharan have low clay activity, their Cation Exchange Capacity (CEC) becomes strongly dependent to SOC (Kater et al. 1992; Bayala and Ouédraogo 2008). In addition, vegetation clearance was reported to have detrimental effects on earthworm which are known to have an effect on soil structure (Hauser et al. 1998, 2012) and faunal diversity and biomass (Ayuke et al. 2011).

All the above mentioned results show that trees/shrubs in agroforestry practices have a direct positive contribution to SOC, justifying the need to encourage the maintenance of trees in farmed lands where the carbon content of soil appears to be the priority limiting factor for crop growth and production (Lal 2011; Bayala et al. 2014). As a consequence, agroforestry is nowadays widely acknowledged as a valuable land management option under various concepts including ever-green agriculture or climate smart agriculture or ecological intensification (Garrity et al. 2010; Doré et al. 2011; Neufeldt et al. 2013; Tittonell and Giller 2013).

4.4 Conclusion

The meta-analysis revealed that agroforestry practices including alley cropping, improved fallow, mulching and parkland increase SOC over treeless plots used as controls. Similarly, except for improved fallows, all practices significantly increased nitrogen over the control. C:N ratios showed the highest values in mulching and parklands as opposed to the alley cropping where nitrogen fixing species are incorporated. Practices that increase the SOC are contributing to re-introducing the ecological functions in the production systems because of the various supporting ecosystem services associated with trees. Therefore, such practices should be encouraged provided the processes governing the optimal utilization of growth resources among the components of the system are well understood. There is also a need to generate context-oriented pathways for sustainable nutrient management and make them available for users and policy makers.

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Chapter 5
Effect of Hill Placement of Nutrients on Millet Productivity and Characteristics of Sahelian Soils of Niger: Analysis of Yield Trend After Three Years of Cropping

Dougbedji Fatondji, Ramadjita Tabo, Tom C. Hash, and Andre Bationo

Abstract Reports from implementation of the low-input mineral fertilizer microdosing technology have shown up to 120% yield increase. However on the acidic Sahelian soils (pH 4–5 (H_2O)) with low carbon content (0.2%), the question is whether applying such small dose would not lead to nutrient mining over years, which ICRISAT set three studies of 3 years each to address. Experiments 1 (2003) and 2 (2008) involved three planting densities, two pearl millet varieties and four fertility management options with removal of crop residue in experiment 1. Experiment 3 (2010) involved the combinations of 4 rates of organic and mineral fertilizers and 10 millet varieties. Both organic and mineral inputs were hill-applied.

In all experiments nutrient hill placement resulted in total biomass increase in the second and third years compared to the control. After 3 years of cropping, yield decrease of -2307 kg.ha^{-1} was observed with the control in experiment 1 between years 1 and 3, while -1238 kg.ha^{-1} was observed with 6 g NPK per hill which was statistically significant. In experiment 3 yield decrease was -1516 kg.ha^{-1} with the control and -648 kg.ha^{-1} with 300 g per hill of organic manure. Soil pH decreased by 0.17 in NPK amended plots whereas it decreased by 0.29 in the others as observed in experiment 1. In all case, biomass decreased but in lower amplitude with organic manure addition.

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Keywords Microdosing technology • Dryland • Nutrient dynamic • Yield decrease • Organic manure • Sahelian soils

Contents

5.1 Introduction

In contrast with the Asian countries that experienced the green revolution, agricultural production in the dryland zones of Africa, has remained stagnant (IFDC 2005–2006). There are many reasons for this. Agriculture is practiced in a fragile and harsh environment characterized by low soil fertility due to inadequate management over years. Most of the soils have lost their physical and chemical properties with crust formation in most cases as well as low nutrient content. According to Bationo et al. (1997) average total N, available P and organic C content of Sahelian soils are 150 mg kg^{-1}, 2.8 mg kg^{-1}, 0.2%, respectively. Harsh climatic conditions are the second cause of low production. Average annual temperature is 35 °C with highly variable and erratic rainfall in time and space. Socio-economic conditions of small scale farmers, such as low asset-base, poor access to inputs and markets, are also a major constraints. As a consequence, while some countries in other parts of the world are using 80 kg/ha of fertilizer, in the dryland of Africa it is limited to less than 8 kg/ha annually. These production environment constraints adversely affect crop and land productivity and make farming inherently risky.

The development of the microdosing technology by ICRISAT and partners aims at helping dryland farmers in managing this risk. Reports from the implementation of this technology have shown up to 120% yield increase (Tabo et al. 2007). Such a high yield increase implies consequent nutrient uptake. Earlier studies have also found insufficient crop residues on-farm after harvest to meet all the multiple purposes of residue use (Baidu-Forson 1995). This affects negatively agricultural productivity and land resource integrity. Because Sahelian soils are acidic (pH 4–5 (H_2O)) and low in nutrients and carbon content (0.2%) the main question remains as whether soil nutrient unbalance would not occur in the long term following the application of the technology. Hence there is a need for additional studies to understand the processes involved in the nutrient dynamics under these conditions and enable the use of such a successful technology for millet production in a sustainable manner.

To address the question of nutrient dynamics and sustainable millet production we conducted three experiments of 3 years each in 2003–2005, 2008–2010 and 2010–2012 which we refer to as experiment 1, experiment 2 and experiment 3. The objectives of experiments 1 and 2 were: to study the sustainability of hill placed mineral fertilizer with regards to crop productivity, soil nutrient dynamic and crop water use. The objectives of experiment 3 were: (i) to study the effect of the combination of hill applied mineral fertilizer and pearl millet genotype on yield; (ii) to determine the optimal combination of varieties, hill placed mineral, and organic amendment options that would lead to better yield and improved water use, and (iii) to test the long term effect of the combination of hill placed mineral and organic amendment and genotypes on pearl millet production and soil nutrients dynamic. In the present paper we will focus on the effect of hill placed nutrients in each experiment on total biomass yield and discuss the trends observed after 3 years of cropping in the three experiments.

5.2 Material and Methods

5.2.1 Site Description

The experiments were conducted at ICRISAT research station at Sadore 13.15°N, 2.17°E, approximately 40 km southwest of Niamey. The long-term averaged rainfall at the station is 550 mm. Mean monthly temperature at Sadore varies between 25 and 41 °C (Sivakumar et al. 1993). The soils are Arenosols (World Reference Base for Soil Resources, FAO 1998), classified as psammentic Paleustalf according to the US soil taxonomy (West et al. 1984). The soil is acidic with relatively high Al saturation. The fields had a gentle 2.5% slope.

5.2.2 Experimental Soil Properties

The soil of the experimental fields is acidic with pH (H_2O) of 4.3, 4.7 and 4.8 for experiments 1, 2 and 3 respectively (Table 5.1). The exchangeable bases (0–20 cm soil depth) is 0.5 cmol kg^{-1}, available P, organic matter content and Cation Exchange Capacity are all low, often at the lowest limits as per Bunasol (1990) indicating low capacity of the soil to prevent leaching of nutrients applied with fertilizers. However the lower level of total N of 174 mg-N/kg (Experiment 1 – Table 5.1) is high according to the same classification, which may be due to the fact that before the experiment set up the fields were left as fallow for more than 10 years, leading to N accumulation.

Table 5.1 Initial chemical characteristics of soils (0–20 cm) in the experimental fields

Soil characteristics	Exp 1	Exp 2	Exp 3
pH-H2O (1:2.5)	4.35	4.77	4.84
Exchangeable base	0.49	0.52	1.89
Total N (mg-N/kg)	174	200	242
Bray P1 (mg-P/kg)	6.69	2.79	4.73
C. Org (%CO)	0.19	0.24	0.27
CEC-Ag (cmol+/kg)	0.11	0.70	

5.2.3 Experimental Design

Experiments 1 and 2 involved three factors, which are: two millet varieties (ICMV IS 99001 and the local landrace), three planting densities (15,000, 10,000 and 5000 hills per ha) and four options of soil fertility management (0 input (control), 2 g DAP per hill at planting and 1 g Urea at stem elongation, 3 g NPK per hill at planting, and 6 g NPK per hill at planting). In experiment 1 all, crop residues were removed after grain harvest. In experiment 2, residues were left in each plot after harvest. Experiment 3 involved three factors including four levels of organic manure management (0 g input, 100 g farm yard manure per hill, 200 g farm yard manure per hill, and 300 g farm yard manure per hill), four levels of mineral fertilizer application (0 input (Control), 2 g DAP per hill at planting and 1 g Urea at stem elongation, 3 g NPK per hill at planting, and 6 g NPK per hill at planting) and ten millet varieties with varying growth habits, growing period length and head shape among which one is the farmer's variety (Local landrace, ICMV IS 99001, ICMV IS 89305, SOSAT-C88, ICRI-TABI, Mil De Siaka (PE05578-C2), (Kado Nio de Mali (PE05572), Sounamau (PE08030), ICMV IS 94206, TCHIOUMA-SOUNA (F8XM1-C2)) (Table 5.2).

Experiments 1 and 2 were conducted in Randomized Complete Block Design with 3 replications. Experiment 3 was conducted in a split plot design in 3 replications. Organic manure management was the main plot and the combinations of mineral fertilizer levels and varieties were applied in the sub-plots. Every year planting was done with the first important rain (rainfall equal or higher than 20 mm), which occurred in June except for 2012 when re-planting of experiment 3 was done on 22nd July due to total seedling destruction of the first planting by grasshoppers. In all three experiments, 6 m × 6 m plot size was used. In experiment 3 within row and between row spacing was 1 m, Whereas in experiments 1 and 2 row spacing depends on planting density treatment. In all three experiments, every year the same plot was used for each treatment.

5.2.4 Data Collection

Before the installation of each experiment, initial soil samples (0–20 cm, 20–40 cm) were collected and analyzed for pH (H_2O), total N, Bray P1, K^+, Ca^{2+}, Mg^{2+}, Na^+,

Table 5.2 Treatments under study in the three experiments, starting dates and planting dates

	Organic fertilizer	Mineral fertilizer	Variety	Planting density	Date started	Planting dates
Experiment 1	NA	No minerals	Sadore local	0.8 m × 0.8 m	2003	27-Jun-03
		2 g DAP + 1 g Urea	ICMV IS 99001	1 m × 1 m		9-Jun-04
		6 g NPK		1.5 m × 1.5 m		1-Jun-05
		3 g NPK				
Experiment 2	NA	No minerals	Sadore local	0.8 m × 0.8 m	2008	18-Jun-08
		2 g DAP + 1 g Urea	ICMV IS 99001	1 m × 1 m		13-Jun-09
		6 g NPK		1.5 m × 1.5 m		4-Jun-10
		3 g NPK				
Experiment 3	No organic	No minerals	Sadore local	NA	2010	26-Jun-10
	100 g per hill	2 g DAP + 1 g Urea	ICMV IS 99001			18-Jun-11
	200 g per hill	6 g NPK	ICMV IS 89305			22-Jul-12
	300 g per hill	3 g NPK	SOSAT-C88			
			ICRI-TABI			
			Mil de Siaka (PE05578-C2)			
			Kado Nio de Mali (PE05572)			
			Sounamau (PE08030)			
			ICMV IS 94206			
			Tchiouma-Souna (F8XM1-C2)			

Organic C and CEC. Additional soil samples were collected in all experiments to evaluate potential changes in these parameters after 3 years of cropping. Only results of experiment 1 are reported in the present paper due to none availability of the results of analysis of the samples of the two other experiments at the time the paper was finalized. For soil sample collection 3 years after cropping the following procedure was adopted: each plot was divided into four equal parts. For each sampling core, soil samples were collected in the middle of each quarter and from the junction of the 4 quadrants giving a total of 5 sampling points. These samples were bulked and a sub-sample was taken.

The crop was harvested at maturity as border rows were eliminated from each side of the plot to avoid border effect. To study crop performance in terms of total biomass production, stover weight, head weight and grain weight per plot were recorded and converted to kg/ha based on the area harvested. Total biomass was calculated as the sum of stover and head yields. Data analysis was done every year for each experiment with ANOVA module in Genstat v13. As the same plots were used every year in all experiments, the data of each experiments were pooled together and analyzed as repeated measurement using Residual Maximum Likelihood (REML) in Genstat V13. To study the effect of nutrient management and the other treatments on total biomass production after 3 years of cropping we calculate the difference between total biomass per plot of year 1 and that of year 3. The resulted data was analyzed with ANOVA module of Genstat V13. In experiment 1 soil sampling to evaluate nutrient dynamic after 3 years of cropping was done in selected plots. As a result, we obtained unbalanced treatment structure which was analyzed with AUNBALANCE module in Genstat v13.

This paper addresses the effects of the treatments tested on total biomass production, which not only involves grain production, but covers farmer preoccupation at household level as it includes the vegetative production, a source of feed for animals, source of energy as well as a construction material. Therefore data interpretation focused on interaction between years and the treatments when they exist. But when there is no interaction the main effect was presented. After this we discussed treatments effect on the difference between total biomass in the first and third year of cropping analyzing the trends observed. As for the treatments, we will address the effect of organic and mineral fertilizer application. The other treatments will a subjects of another paper.

5.3 Results

5.3.1 Rainfall Distribution During the Experimental Years

Cumulative rainfall across the experimental years was similar to the long term average of 550 mm except for 2010 with total rainfall of 387 mm and 2012 when total rainfall was 641 mm (Fig. 5.1). However occurrence of dry spell of variable duration was recorded in all years. Such dry spells were observed in July 2003, in June 2004 and 2005 and in early July 2009 and between late July and early August 2011 (Fig. 5.2a–c, e). Most of these dry spells did not coincide with the reproductive period of the crop when pearl millet is most sensitive to the negative effect of dry spells, however the dry spell between late July and early August 2011 may impact final yield as it occurred at head appearance and flowering stage. In 2011 and 2012, the rainy season started by mid-June but only few rainfall events were recorded at the end of September creating conditions for end of season drought that affects grain filling.

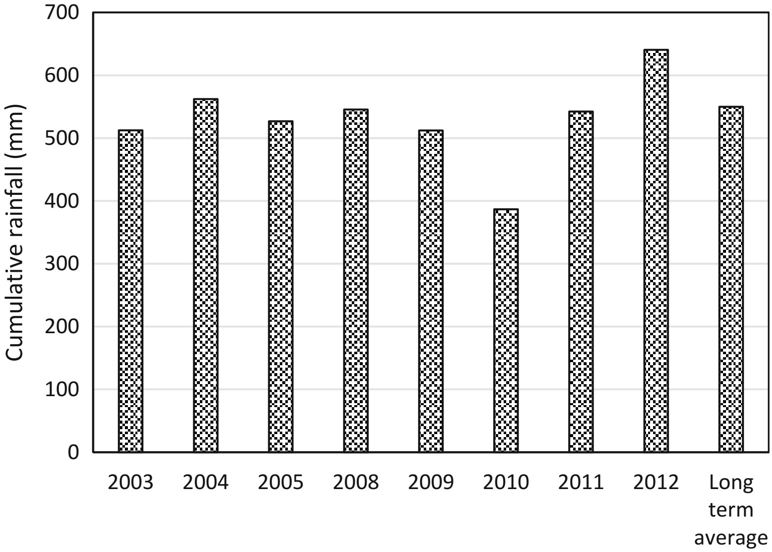

Fig. 5.1 Cumulative rainfall in the experimental years at ICRISAT research station at Sadore and long term average

5.3.2 *Effect of Mineral Fertilizer on Total Biomass Yield Across Years and Experiments*

Treatment main effect was observed in all experiments. Interaction between cropping years and mineral fertilizer application was observed only in experiment 3 which was highly significant at probability level of <0.001 (Table 5.3), however in all years mineral input resulted in increased total biomass production but in varying amplitude. For instance, in year 1 of experiment 1, average biomass increase due to mineral input application was 12% whereas in years 2 and 3 it reached 35% and 45%. The higher average yield increase in years 2 and 3 was due to application of 6 g NPK per hill which contributed significantly as yield increase due to this treatment was 43% and 53% in year 2 and year 3 respectively (Fig. 5.3a).

The same trend was observed in experiment 2 (Fig. 5.3b); however when compared with experiment 1, the effect of mineral input on total biomass yield was more important in year 1 as it reached 28% on average. This trend was similar for experiment 3 but in minor proportions (Fig. 5.3c). Total biomass yield was similar for all levels of mineral fertilizer in year 1 and 2 whereas in year 3, DAP +Urea produced higher biomass than the other treatments. In all experiments, the graphs show increasing effect of mineral input on biomass yield increase compared to the control particularly in year 3. Considering that the field was left uncropped for more than 10 years before the installation of the experiment, this indicates that the benefit from the technology increases with the number of years after a field is returned to production after a fallow period.

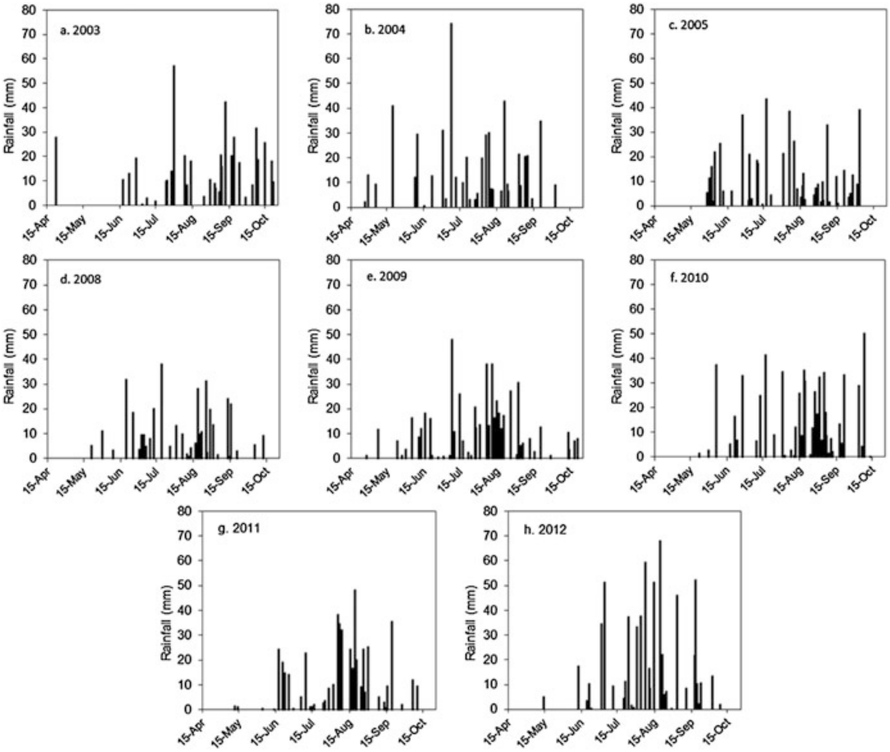

Fig. 5.2 Rainfall in the experimental fields across years (2003–2005; 2008–2010 and 2010–2012)

5.3.3 *Effect of Organic Manure on Total Biomass Yield Across Years and Experiments*

This amendment was applied only in experiment 3. There is high interaction between years and organic manure application (F. Probability < 0.001) (Table 5.3). In year 1 the graph shows similar biomass production for all levels of manure application ranging from 3320 to 3816 kg.ha^{-1} (Fig. 5.4), which could be due to the fertility level accumulated on the field following more than 10 year of fallow prior to the installation of the experiment. However in year 2 and 3, total biomass yield increased with the rate of organic manure application, which could be due a short term residual effect of the fallow in the Sahel as reported in Samaké et al. (2005), from a work in Mali, where 880 kg.ha^{-1} pearl millet grain yield was recorded in a plot after 7 years of fallow but in the following year, pearl millet yield from the same plot was 420 kg.ha^{-1}. Total biomass yield increased in plots with 300 g manure per hill compared to the control was 48% in year 2 and 62% in year 3.

Table 5.3 Table of Residual Maximum Likelihood analysis 3 years data of the three experiments

	Experiment 1: 2003–2005					Experiment 2: 2008–2010					Experiment 3: 2010–2012			
Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr	Wald statistic	d.f.	Wald/d.f.	chi pr
Year	766.71	2	383.35	77.5	<0.001	335.44	2	167.72	96	<0.001	557.07	2	278.54	<0.001
Fert_name	89.66	3	29.88	123.8	<0.001	45.93	3	15.31	46	<0.001	98.4	3	32.8	<0.001
Dens_name	103.67	2	51.83	129.7	<0.001	38.05	2	19.02	46	<0.001	20.96	3	6.99	<0.001
Var_name	38.22	1	38.22	120.4	<0.001	47.17	1	47.17	46	<0.001	138.13	9	15.35	<0.001
Year.Fert_name	5.08	6	0.85	105.4	0.538	5.94	6	0.99	96	0.437	88.13	6	14.69	<0.001
Year.Dens_name	26.32	4	6.57	101.6	<0.001	7.13	4	1.78	96	0.139	19.16	6	3.19	0.004
Fert_name.Dens_name	7.79	6	1.3	134.1	0.263	4.04	6	0.67	46	0.671	9.08	9	1.01	0.43
Year.Var_name	18.49	2	9.23	107.3	<0.001	7.14	2	3.57	96	0.032	295.22	18	16.4	<0.001
Fert_name.Var_name	4.41	3	1.47	138.2	0.226	10.13	3	3.38	46	0.026	22.46	27	0.83	0.714
Dens_name.Var_name	2.56	2	1.28	138.9	0.282	4.04	2	2.02	46	0.144	16.39	27	0.61	0.945
Year.Fert_name.Dens_name	8.05	12	0.67	106.7	0.777	6.72	12	0.56	96	0.869	10.08	18	0.56	0.929
Year.Fert_name.Var_name	5.03	6	0.84	105.1	0.544	5.27	6	0.88	96	0.514	57.05	54	1.06	0.362
Year.Dens_name.Var_name	3.71	4	0.93	109.5	0.451	1.1	4	0.27	96	0.894	39	54	0.72	0.938
Fert_name.Dens_name.Var_name	8.68	6	1.45	139.8	0.201	3.56	6	0.59	46	0.734	80.17	81	0.99	0.505
Year.Fert_name.Dens_name.Var_name	15.43	12	1.28	106.5	0.239	8.23	12	0.69	96	0.761	137.33	162	0.85	0.921

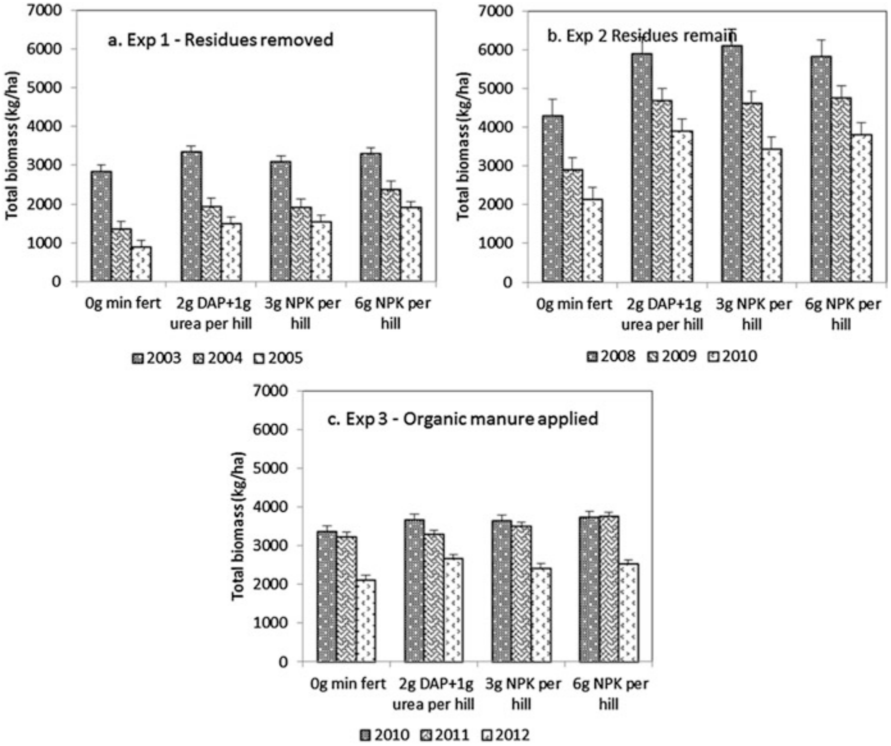

Fig. 5.3 Effect of spot applied mineral fertilizer on millet total biomass yield over 3 years (Means are average over other treatments. Error bars are standard error of difference between mean)

5.4 Pearl Millet Total Biomass Yield Trend After Three Years of Cropping

5.4.1 *Effect of Mineral Fertilizer*

Yield differences were observed between years 1 and 3 in all experiments following mineral fertilizer hill application which were all negative. This means that total biomass yield dropped over years as mineral fertilizer application is concerned. However the results were statistically significant only in experiment 1 (Fig. 5.5). Here we observed that the highest negative difference of -2307 kg.ha^{-1} was observed in the control plot, while the least difference of -1238 kg.ha^{-1} was observed with NPK 6 g per hill. With DAP + Urea biomass yield difference was similar to that of 6 g NPK per hill. The application of nutrient reduced the amplitude of yield drop between year 1 and year 3 in this experiment. But application of 6 g NPK appeared as the most sustainable in this case after 3 years of cropping. There were no interaction between the treatments.

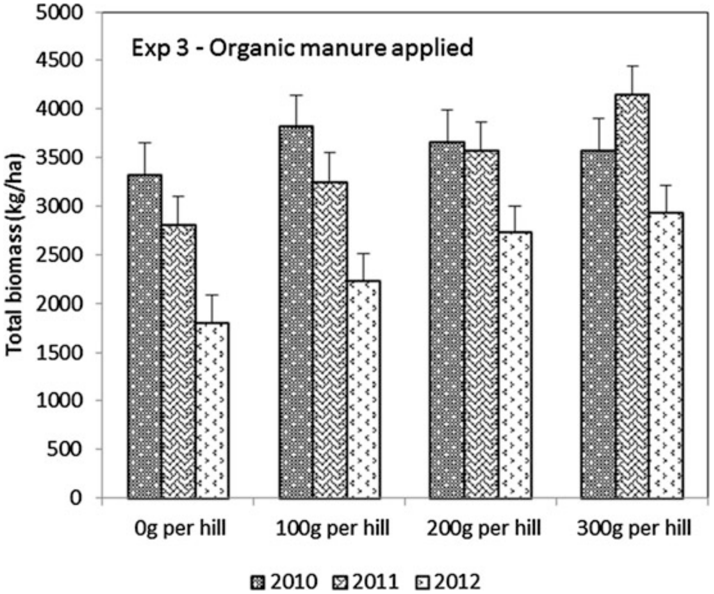

Fig. 5.4 Effect of spot applied organic manure on pearl millet total biomass yield in 3 years (Error bars are standard error of difference between mean)

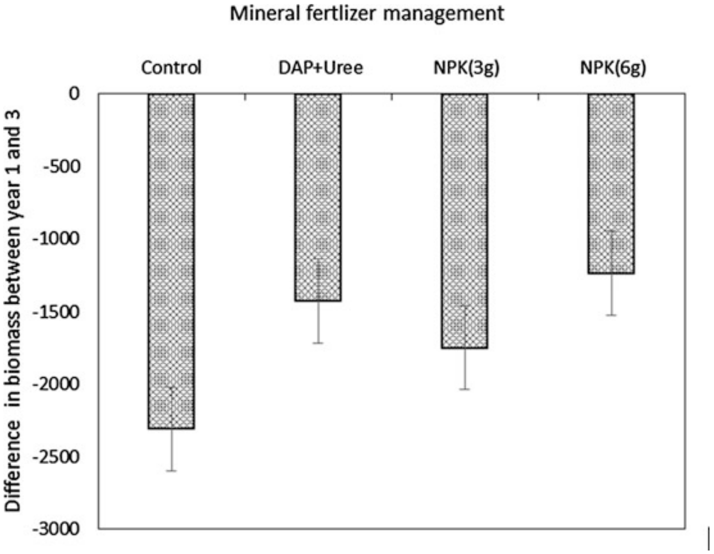

Fig. 5.5 Difference in biomass production between year 1 and year 3. Experiment 1 – Crop residues remove. (Error bars are standard error if difference between means)

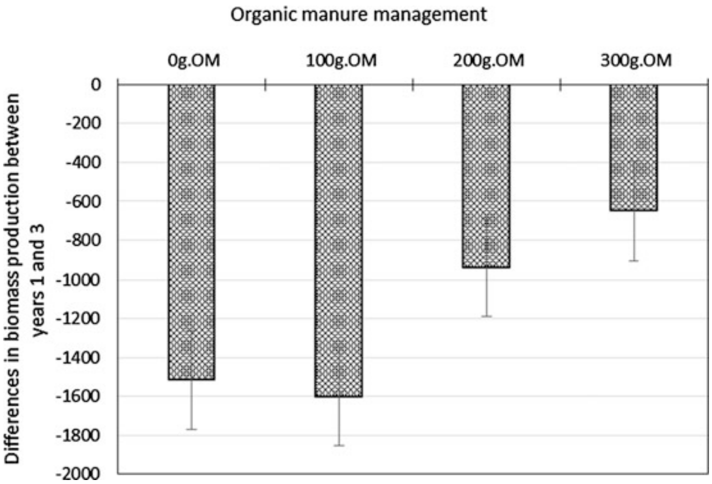

Fig. 5.6 Effect of organic manure on difference in biomass production between year 1 and year 3. Experiment 3. (Error bars are standard error if difference between means)

5.4.2 Effect of Organic Manure

There were no interaction between the treatments in terms of yield difference between Year 1 and 3.

Negative differences were observed in total biomass production between years 1 and 3 following organic manure application indicating tendency in yield drop over year. Yield drop of −1516 was observed without organic manure and −1601 kg.ha^{-1} in plots receiving 100 g Manure per hill (Fig. 5.6), whereas it was −648 kg.ha^{-1} with 300 g manure per hill which appeared as the most sustainable option in this case.

5.4.3 Plant Nutrient Uptake

5.4.3.1 Plant Nutrients Absorption

In the attempt to understand the reason that explain the trends observed we studied plant nutrient export as well as changes in soil chemical properties after 3 years of cropping. For this we calculated nutrient export through straw and grain for the different options of nutrient management in experiment 1, which was done in 2004 and 2005. We realized that in 2004 as well as in 2005, highest level of nutrient uptake (N, P and K) was recorded in the plots amended with 6 g NPK per hill, which was almost two times the uptake under the other treatments (Table 5.4). Nutrient uptake in plots amended with 6 g NPK per hill was higher than the other treatments but was statistically significant only for potassium absorption. In 2005 statistically significant differences were observed between 6 g NPK per hill and the other treatments. Crop

Table 5.4 Effect soil fertility management on nutrient uptake in 2004 (kg/ha)

2004			
Soil fertility management	Nitrogen	Phosphorus	Potassium
Control	12.6	0.74	14.3
2 g DAP + 1 g Urea	13.5	0.86	14.6
NPK(3 g)	13.5	0.83	14.1
NPK(6 g)	21.1	1.22	23.7
Sed (±)	3.90	0.191	3.211
Fprob	0.129	0.085	0.022

Table 5.5 Effect soil fertility management on nutrient uptake in 2005 (kg/ha)

2005			
Soil fertility management	Nitrogen	Phosphorus	Potassium
Control	9.49	0.6341	10.09
2 g DAP + 1 g Urea	11.02	0.807	12.08
NPK (3 g)	10.03	0.7369	13.65
NPK (6 g)	18.5	1.2899	24.58
Sed (±)	2.793	0.1906	3.061
Fprob	0.017	0.016	0.001

nutrients (N, P, K) uptake was similar for the control, 2 g DAP + 1 g Urea and 3 g NPK per hill (Table 5.5). The above observed trend shows that nutrient application and particularly NPK at 6 g per hill induce high amount of nutrient removal.

5.5 Soil Nutrients Characteristics Following Three Seasons of Cropping

So far this investigation was done only in experiment 1. Results of analysis of soil samples from experiments 2 and experiment 3 will be reported in future papers.

In experiment 1, Soil pH decreased in all treatments, indicating possible acidification of the experimental soil (Fig. 5.7a). The rate of pH decrease was more pronounced in the control and the plots in which 2 g DAP + 1 g Urea were applied. Total N level after three years was variable as it was negative only for 2 g DAP + 1 g Urea and NPK at 3 g per hill (Fig. 5.7b). The balance of available P after three years was negative only in the control plot, which could be due to low pH favoring P trapping in the soil complex. As we could observe from the graphs, the higher the pH, the higher was the positive P balance. Plant export from soil with already low P content could have contributed to lowering it further.

Compared to the initial level, Cation Exchange Capacity decreased less in amended plots compared to the control, which is lined with trend observed with regards to pH (Fig. 5.7d).

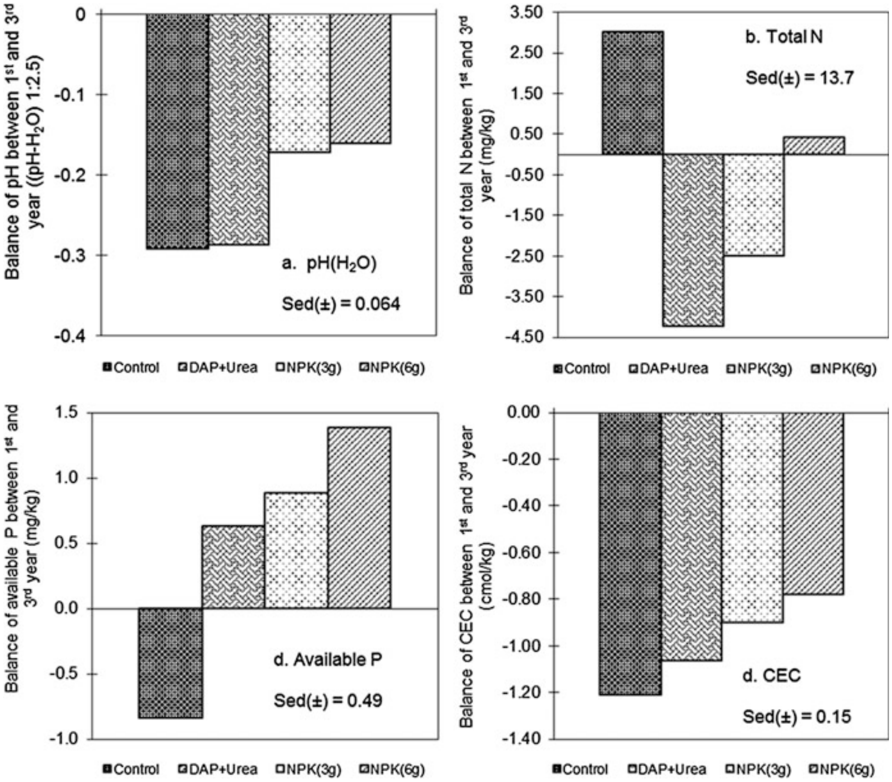

Fig. 5.7 Effect of mineral fertilizer applied as microdose on soil chemical characteristics after 3 years of cropping (2003–2005). ICRISAT research station, Sadore, Niger

5.6 General Analysis

As a photoperiod sensitive crop, the period of planting is crucial for millet crop. Therefore as risk management strategy, famers even practice dry sowing, especially in case there is a delay in the onset of the rainy season. Millet planting normally occurs with the first important rain event in the season (defined climatologically when at least 20 mm rain is received in one event or in three consecutive days and with no dry spell exceeding 7 days within the next 30 days (Sivakumar 1988, 1991). This is important as due to high evapotranspiration, the soil upper layer dries up quickly after rainfall events.

In our study, across experiments and years, planting was done in the window between 1st and 27th June (4 weeks) (Table 5.2), when air temperature was high and photoperiods at their maximum. In the present study, crop was planted in appropriate time except for experiment 3 in 2012 planted on 22nd July when photoperiod was shortening because the whole experiment was replanted due to total destruction of the seedlings following grasshoppers attack. Dry spells were observed but in most cases in period that did not coincide with the reproductive stage except for 2011 when reproduction may be affected. In 2012 when replanting was done, the last rains were received in October and the crops could avoid end of season drought.

After three seasons of cropping we observed that the technology produces a very good results in all three experiments in terms of total biomass yield increase compared to the control. Hill application of organic manure was positive in terms of biomass yield increase and this effect increase from year 1 to year 3. However after 3 years of cropping, total biomass yield decreased with varying amplitude in all treatments even though not statistically significant in all. Reasons for this may be multiple among which for experiment 1, soil acidification inducing the effect of aluminum toxicity that affect particularly root growth (Kretzschmar et al. 1991) can be considered. As we could observe, applying 6 g NPK per hill resulted in the least pH decrease and yield drop but also in positive P balance. The same reason holds for organic manure application in experiment 3. Also plant nutrient removal following input application was high for 6 g NPK per hill. Therefore considering the small amount of nutrient added, we can speculate that nutrient mining may occur. Three years may be quite a short time to observe significant changes in soil nutrient balance; however the trend observed in experiment 1 presumes that soil characteristics especially pH, and CEC may be affected negatively even though with lower amplitude. From this study it appeared that without external input soil characteristics and crop yield are affected negatively after 3 years of cropping. With addition of minerals total biomass decreased but with less amplitude. When crop residues were left in the field biomass yield decrease was also observed but not statistically significant. Therefore for the technology to be sustainable, adequate measures must be taken to sustain the soil fertility level. P being a critical element for plant root growth and subsequent nutrient uptake, the buffering capacity of the soil must be improved to improve available P content. Soil organic matter content must also be improved, which can be achieved with manure application but also with application of crop residues. In the three experiments covered in this paper all these options are tested, each of them for 3 years. Crop residues are used for other purposes such as source of energy but also as construction material in addition to feeding to animals. If at the end of the season they are left in the field, they would be removed due to the roaming character of pastoralism in the region as reported by Baidu-Forson 1995. Our study has shown that total biomass yield drop could be reduced by applying crop residues which according to (Kretzschmar et al. 1991) contribute to reducing aluminum toxicity effect and increasing P availability that results from increased pH but also contribute to enriching the soil by trapping basic cations from dust (Hermann 1996). However in the present study leaving millet stover in the plots did not stop yield decrease over time. Therefore the risk of nutrient mining may still exit.

Results obtained from experiment 3 have shown that total biomass yield increased with the rate of the manure which is in line with the work of Schlecht and Buerkert (2004) who reported linear increase in millet grain with manure rate increase, a result of a work conducted in Niger. In terms of the effect over years, further decrease of the amplitude of yield drop when manure alone is applied or combined with mineral is observed. The beneficial effects of manure on soil characteristics may explain this trend. Many studies have reported increased soil porosity and aggregate stability, increased water infiltration and water holding capacity, decreased eolian soil losses, increased soil organic matter (SOM), pH, CEC and nutrient availability which can lead to sustainable yield and sustained soil fertility over time following manure application (Bationo and Mokwunye1991; Buerkert and Hiernaux 1998; Schlecht et al. 2004).

Until further investigations on the soil chemical characteristics and plant nutrient uptake from the experiments 2 and 3, it appears that in this study inter-annual rainfall variability cannot be considered as the causes for yield drop over years. Nevertheless, the results of soil analysis of experiment 1 show that among others, soil pH may be the main factor leading to the trend observed.

5.7 Conclusion

The present study confirmed the positive effect of hill applied mineral or organic fertilizer and their combination on millet total biomass yield. As observed in experiment 1, this positive effect is associated with high export of plant nutrients. It also revealed that, the effect is more important few years after the field is returned to production after a fallow period. Whether crop residues are maintained on the field or not or in case of combination of the mineral with organic manure, after 3 years of cropping total biomass yield decreased in all treatments even though with varying amplitude. The trend observed in terms of total biomass yield drop show that leaving the residues in the field even though it has minor positive effect is an option to attenuate the negative long term effect on yield. However due to the roaming nature of pastoralism in the Sahelian zone, the risk of all the residues left in the field being removed by grazing animals is high. Therefore measures should be taken so that farmers can benefit from this grazing either by practicing well-structured corralling scheme by signing contract with herd owners, or in case the residues are taken home to be fed to animals, they should make sure equal quantity even if combined with home waste is taken back to the field. This appears as the only mean to sustain soil fertility and drastically reduce the amplitude of yield decrease following hill application of mineral fertilizer.

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Chapter 6
Diagnostic of Mineral Deficiencies and Interactions in Upland Rice Cropping Across Different Agroecologies of West Africa

Brahima Koné, Kouadio Firmin Konan, and N'ganzoua René Kouamé

Abstract Haphazardly fertilization can impaired rice production inducing yield declining in continuous cropping even with high input management. Ecological difference can account for such weakness of upland rice agrosystems. Thus, omission multi-locations trial was conducted in humid forest and guinea savanna of Cote d'Ivoire as well as the sudan savanna of South Mali and a derived savanna of South Benin. A complete fertilizer treatment (Fc) was composed of N (80 k gha^{-}1), P (100 k gha^{-1}), K (50 k gha^{-1}), Ca (50 k gha^{-1}), Mg (50 k gha^{-1}) and Zn (50 k gha^{-1}) while six other treatments were defined by excluding of a specific nutrient (Fc-N, Fc-P, Fc-K, Fc-Ca, Fc-Mg and Fc-Zn) and not fertilized plot was the control. Soil test, rice grain yield and Chaminade index were used for assessing soil nutrient deficiency. Soil K deficiency was often observed according to soil test unless in the subsoil (20–40 cm) coupled with unbalance ratio of cations. Slight to moderate deficiencies of N (savanna ecologies) and P (forest) were observed by Chaminade method and a latitudinal gradient of soil nutrient deficiency was emphasized. Basal fertilizer requirement was identified as NPKMg, NPKZn, NK and NPK in the forest, derived savanna, guinea savanna and sudan savanna respectively with specific composition for each cropping season. Nevertheless, declining yield in continuous cropping was characterizing upland agrosystems indifferently to ecology and fertilizer composition.

Keywords Rice yield declining • Soil nutrient deficiency • Rice mineral nutrition • Agro-ecology

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Contents

6.1 Introduction

Rice (*Oryza sativa* L.) is one of the major food crops in the farming systems of sub-Sahara Africa, with an estimated area of about 6.4 million hectares. The production was 10 million tons annually accounting for 62% from West Africa (Jones 1999). About 80% of rice production surface in West Africa accounted for upland rainfed rice cultivation, especially in humid forestecology (Audebert et al. 1999).

Most of the upland rice in West Africa is produced in slash-and-burn systems in the humid forest zone (WARDA 1999). With increasing land shortages, the length of fallow between periods of cultivation has declined from 12 years in the 1980s to less than 3 years at present, with permanent cultivation emerging in some high population areas (Becker and Assigbe 1995). This intensification of land use in the low-input systems causes declining yield levels, which are associated with a reduced soil N supplying capacity, more weed pressure and widespread P deficiency on the predominant acid Ultisols (Becker and Johnson 1998; Sahrawat et al. 1999; Becker and Johnson 2001).Thus, the yield declining in continuous cropping is a consequence of soil fertility depletion for about 51% of driving factors but, it also occurred even after applying inorganic fertilizers in high input management as well (Pieri 1986).This observation could be related to the effect of unknown limiting factor and/or unbalanced soil nutrient contents resulting to haphazardly practice of fertilization. Thus, we suggested the diagnostic of soil nutrient levels and mineral interactions in the line of site specific fertilizer management concept for overcoming yield declining in intensive rice cropping.

Therefore, the study of soil nutrient deficiencies including N, P, K, Ca, Mg and Zn at least, is need for different agro-climatic zones of West Africa to generate efficient strategy of fertilizer management for continuous rice cropping. The knowledge of nutrients removal by rice plant is also needed for this purpose.

The present study was conducted on ferralsol of humid forest zone and plinthosol of guinea savanna in Côte d'Ivoire. Arenosol of Farako (Southern Mali) and Acrosol (South Benin) were also concerned in order to assess the effects of N, P, K, Ca, Mg and Zn deficiencies on rainfed rice grain yield. The aim was (i) to identify deficient nutrients in soil for rice production, (ii) how far ecological factors can affect nutrient requirement, (iii) how to stabilize rice grain yield in intensive cropping? The overall goal is to improve the sustainability of upland rice cropping in West Africa.

6.2 Material and Methods

6.2.1 *Experimental Sites*

On-farm studies were carried out in Côte d'Ivoire at two locations of humid forest and savanna respectively. Two others sites were concerned in Mali as Farako in South country. The study was also conduction in southern Benin at the experimentation station of Africa Rice Center, Calavi. Figure 6.1 is showing the location of experimental sites and their characteristics are given in the Table 6.1.

During the cropping period (March – June), the rainfall of 849.8 mm (2003), 778.4 mm (2004) and 733.1 mm (2005) were recorded in the humid forest of Guessiho (Côte d'Ivoire). Upto 300 mm of rainfall was recorded at Farako (Mali) only in July during the trial while more sever mid-drought was occurring in August

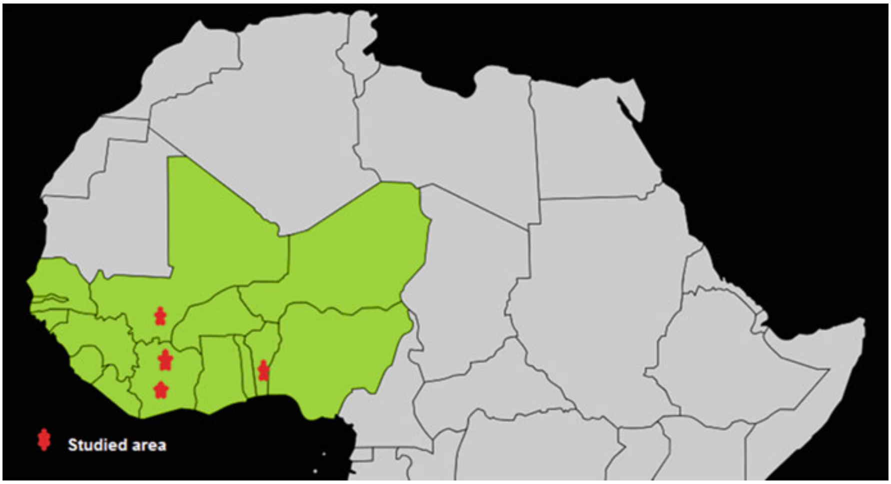

Fig. 6.1 Studied sites location in West Africa

Table 6.1 Studied sites characteristics

Site	Ecology	Rainfall pattern	Annual average rainfall amount (mm)	Temperature (°C)
Guessiho-RCI (6°06 N, 6°00 W, 180 m asl)	Humid forest	Bimodal	1500	28
Boundiali, RCI (9°45 N, 6°30 W, 312 m asl)	Guinea savanna	Monomodal	1200	28
Farako-RM (11°12 N, 5°27 W, 400 m asl)	Sudan Savanna	Monomodal	1200	28
Calavi-RB(6°28′ N, 2°21′ E, 15 m asl)	Derived Savanna	Bimodal	1200	28

(about 60 mm) in the derived savanna of Calavi in Benin. The rainfall amounts of 680 mm and 990 mm were recorded in the guinea savanna of Boundiali in Cote d'Ivoire during the trial.

6.2.2 Experiment Layout

The land was cleaned and tilled manually every year. Fertilizers composed of nitrogen-N (urea), phosphorus-P (super triple phosphate), potassium-K (potassium chloride), calcium-Ca (calcium sulfite), magnesium-Mg (magnesium sulfite) and zinc-Zn (zinc sulfite) were applied as complete fertilizer (Fc) treatment and a specific nutrient was excluded from Fc for the other treatments (Fc-N, Fc-P, Fc-K, Fc-Mg, Fc-Ca and Fc-Zn). A zero fertilizer treatment (0) was set as the control treatment (check). As basal fertilizers, the rates of 30 kg N ha^{-1}, 100 kg P ha^{-1}, 50 kg K ha^{-1}, 50 kg Ca ha^{-1}, 50 kg Mg ha^{-1} and 10 kg Zn ha^{-1} were applied depending on treatment. The rice was sown per hill of three grains spaced by 20 cm in a randomized complete blocks design. Each treatment was set in a micro-plot of 3 m × 5 m with 0.5 m as inter-plot space in a block. Four replications spaced by 1.5 m were considered for a total of 32 micro-plots. At rice tillering and panicle initiation stages, additional applications of 35 kg N ha^{-1} were applied in all treatments except for treatment-0. Two manual weeding were done at 21 and 45 days after rice emergence.

In Cote d'Ivoire, the rice variety WAB 56-104 (*Oryza sativa L.*) was used during three cropping seasons (2003, 2004 and 2005) and NERICA 4 was concerned during 2005 and 2006 in Benin. The experiment duration was limited to year 2004 using NERICA 1.

6.2.3 Soil Sampling and Analyses

Before the experiment, soils were sampled in 0–20 cm and 20–40 cm depths of each micro plot using an augur. The samples were sun-dried, broken and sieved (2 mm) before laboratory analyses. Soil pH(water) and its contents in organic carbon-C (Walkley-Black), total nitrogen-N (Kjeldahl) and available-P (Bray I) were determined. Furthermore, 1 $\underline{N}$ NH4OAc (pH 7.0) was use for K, Ca, and Mg analysis and Zn (perchloric acid). Laboratory analyses were done following the methods described by TSBF (Anderson and Ingram 1993).

6.2.4 Yield Data Collection

At grain maturity stage (about 100 days after emergence), rice was harvested in 8 m ^{2} of each micro-plot excluding the two seeding lines from the border. After threshing, the grains were sun-dry and sieved. Then, grain moisture content was measured before weighting. The grain yield (GY) was determined for corresponding weight for standard moisture of 14%.

Chaminade index-CI (Chaminade 1960) was calculated for each treatment (Fc-x) in relation to the complete fertilizer treatment (Fc) as the ratio of the respective grain yields (GY):

$$\mathrm{CI} = \left[\mathrm{GY}_{(\mathrm{Fc\text{-}x})}/\mathrm{GY}_{\mathrm{Fc}}\right]^{*}100 \tag{6.1}$$

6.2.5 *Statistical Analysis*

Mean values of grain yield-GY and Chaminade index (CI) generated by analyze of variance procedure and they were separated by the test of Student-Newman-Keuls. The statistical analyses were performed by SAS software (Version 10) for $\alpha = 0.05$.

6.3 Results and Discussion

6.3.1 *Ecological Suitability for Rice Production*

Soil physic and chemical properties are presented in Table 6.2. More acidity and content of sand particle are characterizing the soil of the derived savanna of Calavi. In addition to the low content of organic matter observed as consequence of the level of organic-C, intermittent drought as occurring in this ecology (Koné et al. 2009a, b) may have more adverse effect on rice growth and yield. Indeed, soil water holding capacity might be low and soil acidity could have limiting effect on nutrient availability for rice nutrition (Takow et al. 1991; Juo et al. 1995; Rice 2007). However, there were suitable levels for almost the studied soil chemical elements in this environment, except for N (<1 gkg^{-1}) and K (<0.10 cmolkg^{-1}) in 20–40 cm depth. Consequently, the main constraint of upland rice cropping in the studied derived savanna is likely concerning the acidity of the soil, its contents of N, K and sand particle beside of the rainfall irregularity. In fact, there is limited flexibility in sowing date while a mid-season drought is usually observed in August, coinciding with the reproductive stage of rice, hence threatening rice production (Lafitte et al. 2004). Low soil content of Ca (<2 cmolkg^{-1}) may be of concerned since there are unbalance ratios of Ca: Mg that can affect mainly P nutrition of rice (Yates 1964; Koné et al. 2010).

The clay silty soil of the humid forest of Côte d'Ivoire has moderate acidity ($\mathrm{pH} > 5.5$) coupled with low contents of C, N and P. Consequently, K availability for rice nutrition as well as the root development may be impaired by clay content regarding to K-sinking by clay mineral lattice (Koné et al. 2014) and the restriction of soil porosity (Gill et al. 2000).In turn, the heavy rainfall occurring in this agroecology may contribute to improve rice mineral nutrition.

Table 6.2 Chemical characters in the composite sample of 0–20 and 20–40 cm depths before the experiment

	Soil physico-chemical components					
	Benin (Derived Savanna)		Côte d'Ivoire (Forest)		Côte d'Ivoire (Guinea Savanna)	
	0–20 cm	20–40 cm	0–20 cm	20–40 cm	0–20 cm	20–40 cm
$pH_{\text{-water}}$	5.1	5.0	5.6	5.5	6.1	5.6
Clay (g kg^{-1})	126	190	400	520	260	450
Silt (g kg^{-1})	14	20	340	160	250	450
Sand (g kg^{-1})	860	790	240	320	590	390
C (g kg^{-1})	7.20	6.0	8.75	5.6	64	53
N (g kg^{-1})	0.60	0.40	0.87	0.90	10	6
C: N	12	15	10	7	11	12
P (mg kg^{-1})	15	13	4.94	4.03	3.2	3.7
Ca (cmol kg^{-1})	1.25	1.97	0.70	5.40	1.85	1.78
Mg (cmol kg^{-1})	0.70	0.81	0.31	0.21	0.90	0.84
K (cmol kg^{-1})	0.73	0.07	0.23	0.14	0.72	0.07
Ca: Mg	1.7: 1	3: 1	2.5: 1	26: 1	2: 1	2.1: 1
K: Mg	1: 1	9: 100	0.70: 1	0.65: 1	8: 10	7: 84

Data are missing for Farako in Southern Mali

Most balanced soil texture is observed in the guinea savanna ecology of Côte d'Ivoire. In spite of the low soil contents of P (<5 $mgkg^{-1}$), there is suitable levels of organic matter and nitrogen while low content of K only accounts for the subsoil (20–40 cm). Over all, monomodal rainfall pattern observed can contribute for the suitability of this ecology like for the sudan savanna of Mali where soil content of sand particle can affect soil moisture and nutrient stock in rice rhizosphere.

Roughly, unbalance ratios of cations (Ca, Mg and K) are widespread in a manner to be concerned by the nutrition of P, N and Zn (Kouadio et al. 2015a).

However, lowest grain yield is accounting for the derived savanna zone of Benin though about $1tha^{-1}$ is observed for the complete fertilizer treatment and Fc-Mg contrasting with the highest grain yields recorded for the treatments Fc, Fc-Ca, Fc-Mg and Fc-Zn especially, for the humid forest zone and for Sudan Savanna (Fig. 6.2).

6.3.2 *Sustainability of Rice Production*

Table 6.3 is showing a ratio of rice grain yield for given treatment by that of complete fertilizer effect (Fc) as Chaminade index. The mean values for the treatment Fc-K is ranging from 51–75% as moderate to low deficiency of K across the studied zones. This finding underlines widespread occurrence of soil K deficiency in West Africa. In fact, low K content of less than 0.10 $cmolkg^{-1}$ was observed in subsoil (20–40 cm) of almost the studied ecologies while, rice

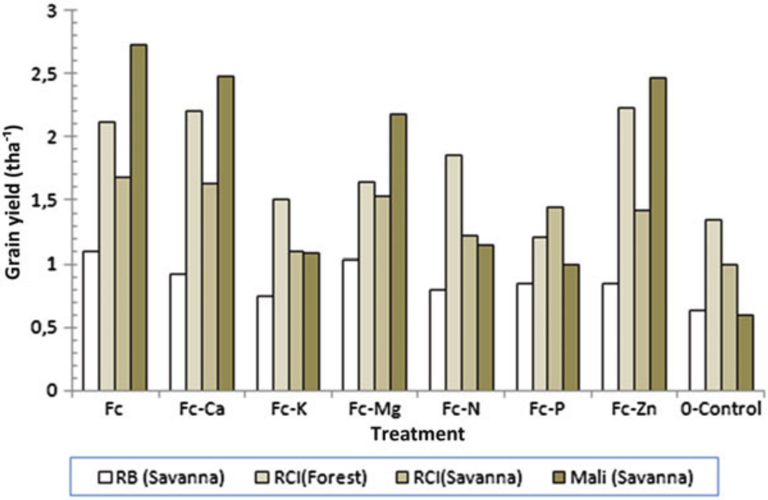

Fig. 6.2 Rice grain yield across sites according to the treatments

Table 6.3 Chaminade index recorded according to the treatment in the studied sites

	Chaminade index (%)			
	Benin (Derived savanna)	Côte d'Ivoire (Forest)	Côte d'Ivoire (Guinea savanna)	Mali (Sudan Savanna)
Fc	100	100	100	100
Fc-Ca	96	114	106	159
Fc-K	73	75	68	51
Fc-Mg	92	85	100	110
Fc-N	106	100	74	57
Fc-P	89	67	93	52
Fc-Zn	95	111	90	101
0-control	79	80	67	32
Mean (%)	91	91	87	83

requirement can reach 0.20 cmolkg^{-1} and about 50–40% of rice root density is below 20 cm depth (Koné et al. 2011).

In addition to K deficiency, slight soil deficiency of P is observed in the humid forest of Côte d'Ivoire as a consequence of P immobilization by oxides and hydroxides of aluminum and iron (Kouadio et al. 2015b). There is extensive documentation of soil P deficiency in the humid forest ecology while, its occurrence in Sudan savanna with highest level of 52% as Chaminade index is new as knowledge improvement. Indeed, because of the highest sand content

Table 6.4 Rice grain yield according to the treatment for every year of cropping in the humid forest of Côte d'Ivoire

	Cote d'Ivoire (Forest)		
	Year1	Year2	Year 3
Treatments	(t ha^{-1})	(t ha^{-1})	(t ha^{-1})
Fc	2.62ab	1.56a	2.03a
Fc-Ca	2.83ab	2.07a	1.71a
Fc-K	2.49abc	0.74c	1.27a
Fc-Mg	2.29abc	1.33abc	1.30a
Fc-N	2.25abc	1.74a	1.59a
Fc-P	1.65c	0.84bc	1.14a
Fc-Zn	3.07a	1.63ab	1.99a
0-Control	1.94bc	0.85bc	1.23a
GM (tha^{-1})	2.39	1.36	1.53

characterizing the encountered Arenosol, nutrients and colloid leaching should be promoted and such process can induce soil N and K deficiencies as observed in there. Hence, there are more soil nutrient deficiencies in the Sudan savanna zone of Mali and soil physic coupled with rainfall should be the main driving factors.

Apart from soil K deficiency, slight N (74%) deficiency is also occurring in the soil of Guinea savanna. In the light of these findings, soil deficiency in N, P and K were often occurring across the studied ecologies unless for one or both of them. When referring to the grand mean of Chaminade index we can notice a latitudinal increasing of soil deficient nutrients for upland rice cropping: this trend is parallel to rainfall regime attesting agroecological relationship with soil fertility management (Christianson and Vlek 1991).

When analyzing the detail of rice grain yield recorded in the humid forest of Côte d'Ivoire (Table 6.4), soil P deficiency is occurring in the first year of cropping and nutrient deficiency is increasing in subsequent years with that of K and Mg in some extend. The difference observed between the yield of the control treatment (0) and that of Fc-N, Fc-K, Fc-P and Fc-Mg does not exceed 0.30 tha^{-1} during the third cropping season though, not statistically significant. This finding is emphasizing the complexity of soil fertility management in continuous rice cropping like previously observed by Friessen (1991) and Hanson (1992).Consequently, declining of rice grain yield is occurring across cropping seasons indifferently to the treatment. However, lowest decreasing trends are accounting for treatment Fc and Fc-Ca likewise for Fc-Mg in the humid forest zone (Fig. 6.3).

Similarly, the first year of rice cropping in the derived savanna of south Benin characterized by low yield (<0.50 tha^{-1}) and no significant difference of treatment (Table 6.5) while significant lowest yields are observed for treatments Fc-N (1.26 tha^{-1}), Fc-K (1.30 tha^{-1}) and Fc-P (1.48 tha^{-1}) as well as Fc-Zn (1.39 tha^{-1}) in some extend during the subsequent cropping season. Of course, Fc-Zn can quantitatively and qualitatively affect rice production (Kouadio et al. 2015a).

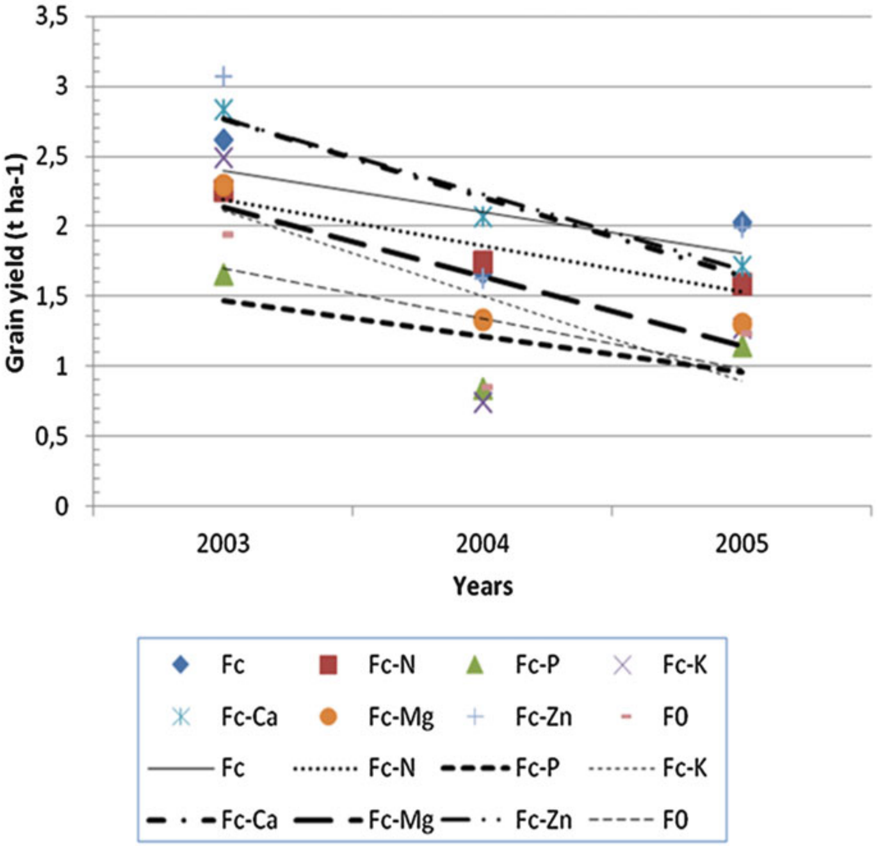

Fig. 6.3 Rice grain yield declining in 3 years cropping (2003–2005) in the humid forest of Côte d'Ivoire

Table 6.5 Rice grain yield according to the treatment for very year of cropping at Calavi in Benin

	Calavi (Derived Savanna)	
	Year1	Year2
Treatments	(t ha^{-1})	(t ha^{-1})
Fc	0.25^{a}	1.93^{a}
Fc-Ca	0.26^{a}	1.58^{ab}
Fc-K	0.20^{a}	1.30^{bc}
Fc-Mg	0.25^{a}	1.81^{ab}
Fc-N	0.34^{a}	1.26^{bc}
Fc-P	0.23^{a}	1.48^{abc}
Fc-Zn	0.32^{a}	1.39^{abc}
0	0.25^{a}	1.02^{c}
GM	0.26	1.47

Letters a, b and c are indicating mean values with significant difference for $\alpha = 0.05$

Table 6.6 Rice grain yield according to the treatment for very year of cropping at Boundiali

	Boundiali (Guinea Savanna)	
	Year1	Year2
Treatments	(t ha^{-1})	(t ha^{-1})
Fc	2.44a	1.12a
Fc-Ca	2.20a	1.07a
Fc-K	1.27a	0.89a
Fc-Mg	2.01a	1.03a
Fc-N	1.74a	0.70a
Fc-P	1.95a	0.96a
Fc-Zn	1.96a	0.88a
0 (Control)	1.18a	0.84a
GM (tha^{-1})	1.82	0.92

Annual rice grain yield recorded in the guinea savanna of Boundiali in Côte d'Ivoire are presented in Table 6.6 according to the treatments. Although the lack of significant difference between the mean values indifferently to the cropping years, the yield observed for the treatment Fc-K (1.27 tha^{-1}) is closer to that (1.18 tha^{-1}) of the control plot in the first year. In turn, closer yields of treatments Fc-K (0.89 tha^{-1}) and Fc-N (0.70 tha^{-1}) to that of the control plot (0.84 tha^{-1}) are observed in the second cropping season.

Definitively, rice nutrient requirement is increasing in the course of rice cropping season in continuous cultivation and wider spectrum of nutrient deficiency is observed with latitude increasing except for the particular ecology of Dahomey gap.

6.4 Conclusion

Fertilizer requirement may be composed of P, PK and PKMg for three cropping seasons respectively while N-fertilizer might support the crop maintenance in the humid forest of West Africa. In derived savanna, NPK and Zn are required while N and K are required for rice production in guinea savanna. In sudan savanna ecology, rice production can be improve by supplying N, P and K –fertilizers.

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Chapter 7
Assessment of Soil Fertility Status and Integrated Soil Fertility Management in Ghana

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Abstract The total land area of Ghana is 23,853,900 ha of which 57.1% (13,628,179 ha) is suitable for agriculture but most of the soils are of low inherent fertility. The coarse nature of the soils has an impact on their physical properties and water stress is common during the growing season. Extensive areas of country's land area particularly the Interior savannah zone have suffered from severe soil erosion and land degradation in various forms. The soil nutrient depletion rates in Ghana is projected as 35 kg N, 4 kg P and 20 kg K ha^{-1}. The extent of nutrient depletion is widespread in all the agro-ecological zones with nitrogen and phosphorus being the most deficient nutrients. Nutrients removed from the soils by crop harvest have not been replaced through the use of corresponding amounts of plant nutrients in the form of organic and inorganic fertilizers. There is therefore a steady decline in crop yield levels and increased food production is presently due mostly to extension in the area under cultivation. Overall percentage increase in cultivated area between 2000 and 2008 is about 17.3% (SRID 2008). The average yields of most of the crops are 20–60% below their achievable yields, indicating that there is significant potential for improvement While Ghana has one of the highest soil nutrient depletion rates in SSA, it has one of the lowest rates of annual inorganic fertilizer application – only 8 kg per hectare.

An increase in food security requires increased productivity strategies that will raise yields for most crops toward their achievable levels, mostly by the adoption of intensive and improved technologies, including the use of fertilizers, improved seeds and best management practices. While African policy makers and International donors recognize the urgency of raising fertilizer use by small holder farmers, for achieving both agricultural growth and poverty alleviation objectives, there is little consensus on the most appropriate policy and programmatic course of action. Most efforts to raise fertilizer use in SSA over the past decade have focused on fertilizer subsidies and targeted credit programmes with hopes that these programmes could later be withdrawn once the profitability of fertilizer use has

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been made clear to newly adopted farmers and once they have become sufficiently capitalized to be able to afford fertilizer with their own working capital. Relatively little emphasis has been given to improving the profitability of fertilizer use through understanding the most productive levels and combinations of nutrient input for various agro ecological areas, management practices and market options. Inorganic fertilizer does not improve agricultural productivity in isolation. Information on the fertility status and agricultural potential of the soils are also required. Complementary inputs such investment in soil and water conservation for efficient end optimal nutrient uptake is also important. Improved soil fertility management through increased levels of fertilizer use, increased use of available organic soil amendments, and improved farm management practices, together with the use of improved seed, can result in positive gains in farm productivity. This increase in productivity is demonstrated by the SAWA technology in rice production where yield on farmers' fields increased from 1 ton/ha to 5 tons/ha (Buri et al. 2007). There is lack of information on the profitability of the different soil-crop-fertilizer combinations that could be employed in the different parts of the country. The lack of such information on crop-fertilizer profitability across the country means that farmers cannot tell how much they stand to gain or lose by applying a particular type of fertilizer on a particular crop. This increases their risk and creates a disincentive for use of fertilizer. Information about profitability levels can serve as an incentive for inorganic fertilizer use. Most simply, expected Value Cost Ratios (VCR) from fertilizer use can guide farmers' decisions. Knowledge of soil characteristics and processes regulating nutrient availability and supply to crops is essential to raise productivity per unit of fertilizer nutrient applied. The recommendation of the African Fertilizer Summit (2006) to increase fertilizer use from 8 to 50 Kg/ha nutrients by 2015 reinforces the importance of fertilizer for increasing crop productivity and attaining food security and rural wellbeing in Ghana. The impact of this target will however vary depending upon the agronomic efficiency of applied fertilizer. This efficiency varies across ecological zones, farms and fields within farms and greatly affects the returns to the recommended 50 Kg/ha. The application of insufficient fertilizers and inappropriate nutrient conservation practices by farmers contribute to accelerating the rapid decline in soil fertility. The efficient uses of both inorganic and organic fertilizers, through Integrated Nutrient Management approach, will form an important element of a holistic approach for sustainably increasing crop production in Ghana.

Contents

7.1 Introduction

The agricultural sector of Ghana contributes about 40% to the country's gross domestic product (GDP), employs over half of the labour force and also provides raw materials for industrial growth and development (GoG 2010). The GDP growth rate was 4.4%, while that of the agricultural growth rate was 4.2% in the year 2000–2003. In 2003–2007, the GDP growth rate increased to 5.8%, while that of the agricultural growth increased to 5.2% (The State of the Ghanaian Economy in 2008). From 2006 until 2014 the GDP averaged 2.14%, while the agricultural sector contracted for the first time by 2.9% (GSS 2014).

Consequently various policies and programs have been put in place to drive this growth process. For example the Ghana Poverty Reduction Strategy (GPRS 1 2003) and Growth and poverty Reduction Strategy (GPRS II 2008) documents which identified agriculture as the most important driver for poverty reduction in Ghana. Other programmes that were formulated to improve agricultural production included the Food and Agricultural Sector Development Policy (FASDEP I & II 2003–2008, 2011–2015), implemented through the Medium term Agriculture Sector Investment Plan (METASIP) and the Accelerated Agricultural Growth and Development Strategy (AAGS). The METASIP targets 9.6% agricultural growth rate and halving poverty by 2015 through the allocation of 10% of the national budget to Agriculture.

Agricultural production in a region can increase through two ways: through higher production per unit of land, or by increasing the area cultivated. The dramatic increases in agricultural production in Asia known as the Green Revolution were mostly through higher yields. But Africa's far lower increases have mostly been through expansion of the cultivated land.

The fact that fertilizer use per unit area in Africa is less than 10% of that in Asia explains much of the contrasting trends in these regions. African countries including Ghana today face not only the challenge of increasing agricultural production with scarce overall resources but must raise productivity in a way that conserves the natural resource base and prevents further degradation that has characterized African soils for generations. Soil nutrient mining, the result of overexploitation of agricultural land, is in fact consumption of a key component of the soil's natural capital. The propensity for nutrient mining of Africa's agricultural land and the severity of its consequences are the highest in the world. Soil nutrient mining is usually associated with low agricultural production and land productivity under severe constraints of poverty in terms of physical capital (infrastructure) and human capital (health and education). Continued nutrient mining of soils with no or low external inputs would mean a future of even increased poverty, food insecurity, environmental damage, and social and political instability.

It is evident that, in order to maintain and increase food production, efforts to prevent soil degradation must become a top priority of our global society. Current population models predict a global population of between 8 and 10 billion in the next 50 years (Bongaarts 2009; Lutz et al. 2001) and a two-fold increase in food demand (Alexandratos 1999; Tilman et al. 2002). If mismanagement of soil resources continues to diminish the fertility of the soil and the amount of productive arable land (Pimentel 1995), then we will have lost a precious and essential pillar of sustainable agriculture (Tilman 1999). Sustainable agriculture is an approach to farming that focuses on production of food in a manner that can be maintained with minimal degradation of ecosystems and natural resources. This sustainable approach to agriculture strives to protect environmental resources, including soil, and provide economic profitability while maintaining social equity (Brodt 2011).

Ghana has a relatively large amount of cultivated land per capita; however, most of these lands are characterized by poor fertility and are subject to degradation. To reverse the declining trend in land productivity (crop yield) and ensure food security, soil management is crucial. One way to address the twin problem of low agricultural productivity on one hand and environmental degradation on the other is fertilizer use – both organic and inorganic, especially in low income countries where fertilizer use is lowest (Smaling et al. 2006). Inorganic fertilizer use in grain production, for example, can increase output by 40–60% (Roberts 2009). Application of organic fertilizer from animal and/or plant residues on the other hand provide some nutrients besides playing a crucial role in improving soil moisture conservation, especially when combined with conservation tillage practices that protect soil structure, reduce erosion and runoff, and promote soil biological functions important for soil productivity (Agwe et al. 2007). Nonetheless, a combination of organic and inorganic fertilizer for integrated soil fertility management is the most ideal in increasing yield in the short term, while maintaining long term soil fertility (Alley and Vanlauwe 2009). Indirectly, use of fertilizers lead to higher economic growth and poverty reduction through increased agricultural productivity and output (Dethier and Effenberger 2011). This is particularly more evident in Sub-Saharan Africa (SSA) countries where agriculture is the primary sector and source of livelihood to the majority of the population (World Bank 2007). Nevertheless, if not well managed, long-term use of fertilizer – whether organic or inorganic, results in inefficiencies of input use, leading to soil degradation, lower productivity and potential damage to the environment (FAO 1994).

The use of fertilizer in crop production in Ghana remains low; at about 8 Kg/ha (Fuentes et al. 2012), despite the fact that nutrient depletion is among the highest in Africa (Henao and Baanante 2006). Although Ghana is among countries in SSA that signed the Abuja declaration of increasing fertilizer use from the continent average of 8 kg per hectare to at least 50 kg per hectare per annum by 2015 (African Union 2006), there is little indication that the country is about to attain fertilizer use intensity of at least 15 kg of per hectare per annum. According to Smaling et al. (2006), unless radical interventions occur, projected inorganic fertilizer consumption growth in SSA until 2030 will remain at 1.9% per annum.

While there has been considerable research and policy analysis on fertilizer use in Ghana, there remain knowledge gaps, on the state of fertility of Ghanaian soils; the yield response to fertilizer for major crops, the profitability of fertilizer use, and the likely effects of changing climatic conditions on the profitability of fertilizer use. This report therefore presents an overview of the soil fertility status and integrated soil fertility management in Ghana.

7.2 The Soils Resource Base of Ghana

The soils of Ghana are formed on very old landscapes and highly weathered except in areas over recent alluvium or where erosion has exposed the basement rocks. They are therefore inherently low in fertility especially in weatherable mineral reserves. The topsoils are predominantly loamy sands and sandy loams especially where the soils developed over granites and sandstones. On other geological materials, selective erosion also results in similar topsoil textures. The subsoils, on the other hand, have relatively heavier textures varying from gritty sandy clay loams/sandy clays to clays due to clay migration down the profile or selective erosion in surface horizons. Clay textured soils are normally common in the valley bottoms, which are ideal for rice cultivation.

Sedentary soils that developed from pegmatitic rocks (that is presence of large quartz veins) may contain abundant coarse material either as gravels or stones especially in the subsurface horizons. The subsoils also often show features of accumulation or concentrations in the form of iron and manganese concretions and nodules (FAO/WBCP 1991).

On the basis of the length of the growing period developed by FAO, the country is covered by six agroecological zones. The major soils in each zone classified according to the World Reference Base for Soil Resources (WRB) (IUSS Working Group WRB 2006) are outlined in Table 7.1 below.

Aluvial soils (Fluvisols) and eroded shallow soils (Leptosols) occur in limited extent in all the ecological zones and were not indicated in the table above. Table 7.2 shows key attributes about the major soils since Table 7.2 does not give clear appreciation of the nature of soils to readers.

The main constraints of the soils and their suitability for crop production are provided in Table 7.3.

Table 7.1 Major soils in the six agroecological zones in Ghana

Item	Agroecological Zone	Major soil types (Reference Soil Groups (WRB)
1	Forest-Savanna Transition	Lixisols, Nitisols, Plinthosols and Cambisols
2	Guinea Savanna	Plinthosols Lixisols, Planosols, Luvisols and Gleysols
3	Sudan Savanna	Lixisols, Plinthosols, Luvisols and Gleysol
4	Coastal Savanna	Vertisols, Solonchacks, Luvisols, Cambisols, Gleysols, Solonetz and intergrades
5	High Rainforest	Ferralsols, Acrisols, Nitisols and Gleysols
6	Semi-Deciduous Forest	Acrisols, Lixisols, Nitisols and Gleysols

Table 7.2 Simplified guide to Reference Soil Groups that commonly occur in Ghana

Item	RSG	Key attribute
1	Acrisol	Soils with clay-enriched subsoil having low cation exchange capacity and low base status (BS $<$ 50%)
2	Lixisols	Soils with clay-enriched subsoil having low cation exchange capacity but high base status (BS $>$ 50%)
3	Alisols	Soils with clay-enriched subsoil having high cation exchange capacity but low base status (BS $<$ 50%)
4	Luvisols	Soils with clay-enriched subsoil having low cation exchange capacity and low base status (BS $>$ 50%)
5	Cambisols	Moderately developed soils soil profiles
6	Vertisols	Soils with limitations to root growth due high clay content and shrink swell phenomenon under alternating wetting and drying condition
7	Leptosols	to thin soils or abundant gravels and stones
8	Solonetz	Soils with limitations to root growth due to high content of exchangeable Na
9	Solonchack	Soils with limitations to root growth due to high concentration of soluble salts
10	Plinthosol	Occurrence of plinthite (accumulation and redistribution of iron) within 50 cm from the soil surface and usually cemented or pisolithic
11	Ferralsols	Soils distinguished by dominance of kaolinite and iron and aluminium oxides
12	Nitisols	Low activity clay, P-fixation, stronly structured withmany iron oxides
13	Planosol	Stagnating water, with more than doubling of clay content in underling layers
14	Gleysols	Groundwater affected soils

Source: Modified After (IUSS Working Group, WRB 2014)

7.2.1 *Fertility Status of Ghanaian Soils*

Most of the soils are developed on thoroughly weathered parent materials. They are old and have been leached over a long period of time especially in the humid (High rain forest and Semi-deciduous) zones (Benneh et al. 1990). Organic matter content is generally low due to high mineralization under warm and humid climate and continuous cropping especially in the Sudan savanna zone. In general the soils have low buffering capacity due to the low mineral reserves, low organic matter content and coarse-textured topsoils. Nutrient retention is also low since the predominant clay mineral is kaolinite (cation exchange capacity is less than 10 $\text{cmol}_{(+)}\ \text{kg}^{-1}$ clay). The soils are consequently of low inherent fertility.

The two most deficient nutrients are nitrogen and phosphorus particularly because of the very low organic matter content. The build-up of any amount of organic matter is further constrained by the regular burning of crop residue and/or competitive use of these residues for fuel, animal feed or building purposes. The low vegetative cover during the long dry season also renders most of the soils in the

Table 7.3 Main constraints of the soils and their suitability for crop production

Agroecological Zone	Major soil type	Main constraints	Major crops/use
Forest-Savanna Transition	Lixisols, Plinthosols	Low nutrient status, high P-fixation potential	Cashew, maize, cowpea, cassava, yam
		Poor natural soil fertility caused by strong weathering, waterlogging in bottomlands and droughtiness on petroplinthite,or pisoliths (ironstone gravels)	---------------do---------------
Guinea Savanna	Lixisols, Plinthosols, Planosols,	Same as above	Maize, sorghum, cowpea, cotton, yam
		Same as above	
		Low nutrient status and temporal waterlogging	Groundnuts, cowpea
			Rough grazing
Sudan Savanna	Lixisols, Plinthosols, Luvisols	Same as above	Maize, sorghum, millet, cowpea
		Same as above	
		Droughtiness of topsoil	Groundnut and cowpea
Coastal Savanna	Vertisols, Solonchacks, Solonetz	Workability limitations, Low phosphorus availability, susceptibility to alkalinization and salinization, high potential of nitrogen losses	Rice, sugar cane
		Accummulation of salts	Grazing
		Presence of clay pan, high alkalinity	
High Rainforest	Ferralsols, Acrisols,	Low nutrient supply and retention capacity, low exchangeable basic cations, fixation of phosphorus, aluminium toxicity at pH < 5.0, molybdenum is often deficient for BNF by legumes	Oil palm, para rubber, and cassava
Semi-Deciduous Forest	Acrisols, Lixisols, Nitisols	High leaching, high potential to fix phosphorus, boron deficiency, poor internal drainage, poor rootability of the subsoil, high potential of erosion in weakly structured surface horizons	Cocoa, oil palm, plantain, cocoyam, cassava, maize cowpea, yam
		Same as above	---------------do---------------
		High potential for P-fixation	---------------do---------------
	Fluvisol and Gleysols	Poor drainage, high potential of Aluminium and iron toxicity	Rice and occasionally sugar cane in southern Ghana

savanna zones susceptible to erosion during the rainy season. This, in turn, exacerbates the low fertility problem.

The sustainability of good crop yields is therefore closely linked with the careful management of the soils with the objective of preventing and controlling erosion, increasing their organic matter content, and replacing plant nutrients lost through erosion and crop uptake

The average fertility status of soils of the different agro ecological zones is presented in Tables 7.4, 7.5, 7.6, 7.7, 7.8 and 7.9.

7.2.1.1 High Rainforest

The main soils are Acrisols, Ferralsols and Gleysols All the soils exhibit chemical properties that show little variation from each other. Chemically they are not different, physically they are? They are severely leached of bases and as a result the pH values vary from 3.8 to 4.5 with an average value of about 4.0 which restricts the choice of crop. Soil organic carbon is generally more than 1.0% in the topsoil (0–15 cm) and sharply decreasing to less than 1.0% in the subsoil. Topsoil organic carbon values range from 1.5 to 4.2%. Total N varies from about 0.4% in the topsoil to as low as 0.04% in the subsoil. Topsoil total N values range from 0.1 to 0.4%. Available phosphorus levels are low due to the highly weathered soils deficient in apatites. Available P values range from about 5.0 mg/kg in the A horizon decreasing to about <0.1 mg/kg in the subsoil. Potassium is not as deficient as nitrogen and phosphorus in these soils. Available potassium values of the A horizon range from 60.0 to 150.0 mg/kg depending on the soil management practice. The soils in these zone are suitable for the cultivation of both tree and arable crops including, Coconut, oil palm, citrus rubber, cassava, and pineapple.

If you identify the normal range for various nutrients in the para following the table, you then need not repeat the numbers here. You can then focus on characterizing the nature of soils.

7.2.1.2 Forest – Transition

The dominant soils in this zone are Dystric Nitisols, Chromic Lixisols, and Ferric Acrisols. The pH ranges from 5.1 to 6.4 in the A horizon which declines to low values in the subsoil. Soil organic carbon values in the A horizon range from 0.6 to 1.0% and decline with soil depth to very low levels. Total nitrogen values are associated with soil organic carbon values. Total nitrogen values range from 0.04 to 0.16% in the A horizon and declines to low levels in subsoil. Available phosphorus values range from 0.30 to 4.7 mg/kg declining to low levels because most nutrients are associated with soil organic carbon accumulation which is limited to the A horizon. Why should we care about the top and subsoil differences? Rice, cowpea, maize, cassava, vegetables, groundnuts, soybean, yam, AND mango. What about these?

Table 7.4 Soil fertility status of the high rainforest agro-ecological zones

Agro-ecological zones	Soil parameter	Value	Remarks	Major crops				
				Cereals	Starchy crops	Legume	Vegetables	Tree crops
High Rainforest	Soil pH	3.8–4.5	Extremely acid to strongly acid	Maize, rice	Cassava, coco-yam, plantain	–	Pepper, okra, eggplant	Citrus, coconut, oilpalm, rubber
	Organic C	1.52–4.24	Medium to high					
	Total N	0.12–0.38	Low to medium					
	Available P	0.12–5.42	Low					
	Available K	63.57–150.41						

Table 7.5 Soil fertility status of the forest-transition agro-ecological zones

Agro-ecological zones	Soil parameter	Value	Remarks	Major crops				
				Cereals	Starchy crops	Legume	Vegetables	Tree crops
Forest-Transition	Soil pH	5.1–6.4	Moderately acid to slightly acid	Maize, rice	Cassava, cocoyam, plantain	Cowpea	Pepper, okra, eggplant, tomato	Citrus, coffee, oilpalm, cashew
	Organic C	0.59–0.99	Low					
	Total N	0.04–0.16	Very low to low					
	Available P	0.30–4.68	Low					
	Available K	58.29–72.53						

Table 7.6 Soil fertility status of the semi-deciduous forest agro-ecological zones

Agro-ecological zones	Soil parameter	Value	Remarks	Major crops				
				Cereals	Starchy crops	Legume	Vegetables	Tree crops
Semi-Deciduous Forest	Soil pH	5.5–6.2	Moderately acid to slightly acid	Maize, rice, sorghum	Yam, cocoyam, plantain, cassava	Cowpea, groundnut	Tomato, pepper, okra, eggplant	Citrus, coffee, cashew
	Organic C	1.59–4.80	Medium to high					
	Total N	0.15–0.42	Low to medium					
	Available P	0.36–5.22	Low					
	Available K	62.01–84.82						

Table 7.7 Soil fertility status of the Coastal Savanna agro-ecological zones

Agro-ecological zones	Soil parameter	Value	Remarks	Major crops				
				Cereals	Starchy crops	Legume	Vegetables	Tree crops
Coastal Savanna	Soil pH	5.6–6.4	Moderately acid to slightly acid	Maize, rice, sorghum, millet	Yam, cassava	Cowpea, groundnut, bambara	Tomato, pepper	Sheanuts, cashew
	Organic C	0.61–1.24	Low to high					
	Total N	0.05–1.16	Very low to very high					
	Available P	0.18–3.60	Low					
	Available K	48.02–58.71						

Table 7.8 Soil fertility status of the Guinea Savanna agro-ecological zones

Agro-ecological zones	Soil parameter	Value	Remarks	Major crops				
				Cereals	Starchy crops	Legume	Vegetables	Tree crops
Guinea Savanna	Soil pH	6.2–6.6	Slightly acid	Maize, rice, sorghum, millet	Sweet potato	Cowpea, groundnut, bambara	Tomato, onion	Sheanuts
	Organic C	0.51–0.99	Low					
	Total N	0.05–0.12	Very low to low					
	Available P	0.18–3.60	Low					
	Available K	46.23–55.27						

Table 7.9 Soil fertility status of the Sudan Savanna agro-ecological zones

				Major crops				
Agro-ecological zones	Soil parameter	Value	Remarks	Cereals	Starchy crops	Legume	Vegetables	Tree crops
Sudan Savanna	Soil pH	6.4–6.7	Slightly acid	Maize, rice	Cassava	Cowpea	Tomato, shallot	Coconut
	Organic C	0.48–0.98	Low					
	Total N	0.06–0.14	Very low to low					
	Available P	0.06–1.80	Low					
	Available K	36.96–44.51						

Source: Adapted from 2005 Annual Report, CSIR-SRI and Fening et al. (2005a, b) and Gerken et al. (2001)

Nothing on the availability of major nutrients. Can we have uniform information for all zones. We can then even summarize the information in a table.

7.2.1.3 Semi-Deciduous Forest

The dominant soils in this zone are the Acrisols and Lixisols with Lithosols (Leptosols), Luvisols and Gleysols occurring in limited areas as marginal soils. The pH ranges from about 5.5 to 6.2 in the A horizon and declines with soil depth to about 4.8. The average soil organic carbon content is more than 1.0% (i.e. 1.6–4.8%) in the A horizon which falls below 1.0% in lower horizons. Total nitrogen is associated with soil organic carbon. Total nitrogen levels range from 0.15 to 0.24% in the A horizons. Available P levels are also low and concentrated in the A horizon and ranging from 0.4 to 5.2 mg/kg soil.

Available potassium values range from 62.0 to 100.0 mg/kg soil and declines to lower values in the subsoil. Some of the suitable crops for the soils in this zone are: Cocoa, coconut, oil palm, rice, sugar cane, cassava, cocoyam, yam, plantain, citrus, maize, banana, vegetables, mango and avocado. Are there crops unsuitable for this area?

7.2.1.4 Coastal Savannah

The major soils encountered in the coastal savanna zone include Lixisols, Vertisols and Solonetz and Vleisols. They have generally low organic matter contents (0.6–1.2%) in the A horizon. The soil reaction is near-neutral or moderately acidic to acidic (5.6–6.4) in the topsoil and become increasing alkaline with depth because of the accumulation of calcium carbonate concretions. Organic carbon content is less than 1.0% with a range of about 0.6 to 1.2%. Total nitrogen is less than 0.1% with a range of 0.05 to 0.16%. Available phosphorus values are low ranging from 0.3 to 4.1 mg/kg due to low apatite content of soil and partly due to fixation on Fe-Mn concretion surfaces. Potassium availability is low due to the presence of vermiculite in some of the soils causing K-fixation. Available potassium values range from 48.0 to 58.7 mg/kg. The following crops are normally grown on the soils in this zone. Rice, cotton, sugar cane, cowpea, vegetables, maize, cassava, shallots, and coconut. Are they suitable?

All of this is merely repeating what is in the table.

Instead, unusually high or low ranges can be identified in the table itself.

And explain why top and subsoil differences in nutrient content matter. Does it have anything to do with suitability of crops or suggest degradation?

7.2.1.5 Guinea Savannah

The dominant soils encountered in the Guinea savannah zone include Ferric Acrisols, Lixisols, Nitisols, and Plinthosols. These are shallow to very shallow reddish brown to brown, concretionary, and medium to light textured soils susceptible to erosion. We didn't see anything about the depth of soils in other zones. The organic carbon content is low ranging from about 0.5 to 1.0% in the topsoil. Total nitrogen content is generally less than 0.1% (0.05–0.12%). Available phosphorus values are low (0.2–3.6 mg/kg) and available potassium values are also low (46.2–55.3 mg/kg). Rice, cotton, sugar cane, cowpea, vegetables, maize, cassava, vegetables, groundnuts, soybean, yam, mango, sorghum, millet, usually grown or suitable?

7.2.1.6 Sudan Savannah

The soils encountered include Ferric Lixisols, Luvisols, Eutricalcicgleysols. They have generally low organic carbon content (0.5–1.0%) due to insufficient accumulation of biomass under savannah conditions. Soil reaction ranges from near neutral (6.4–7.0) in the A horizon to moderately acidic with depth (in the subsoil). Available phosphorus values are low (0.1–1.8 mg/kg) due to low soil apatite content and fixation on iron concretions. Available potassium content is also low (37.0–44.5 mg/kg). The nature of the soils make it suitable for the cultivation of these crops; Rice, cotton, sugar cane, cowpea, vegetables, maize, cassava, vegetables, groundnuts, soybean, yam, mango, sorghum, millet.

Please expand table two by adding two columns: one for key characteristics of the soil (such as, "shallow soils prone to erosion") and the other for suitable crops.

Indicate unusually low levels by shading the squares.

Discuss the major differences between zones in one or two paragraphs. Explain why top and sub soil differences mater and how they vary among zones.

7.2.2 Soil Degradation and Nutrient Depletion

Sustainable agricultural production depends primarily on productive soils, however the soil resources of the country are being degraded as a result of the interaction of both natural and anthropogenic factors. In order to meet the future food needs of Ghana, while reducing poverty and protecting the environment would require halting and reversing soil degradation through restorative measures of soil, water, nutrient and crop management.

The major processes or types of soil degradation in Ghana are physical (erosion, compaction, crusting and iron pan formation), chemical (depletion of nutrients, salinity and acidification) and biological (loss of organic matter).

Table 7.10 Erosion on Bare Farm Plots within the agro-ecological zones of Ghana

Agro-ecological zone	Soil series	Slope (%)	Soil loss (t/ha)	Runoff % of rainfall
Semi-Decíduous	Asuansi (Ferric Acrisol)	7.5	186.9	47.0
Forest-Savanna Transition	Bediesi (RhodicNitisol)	3.0	12.8	38.0
Guinea Savanna	Nyankpala (Ferric Lixisol)	2.0	0.9	11.5
Coastal Savanna	Toje (RhodicNitisol)	2.5	0.6	18.0

Source: Adapted from Bonsu (1979)

7.2.2.1 Soil Erosion

Soil erosion is one of the most potent degradation processes affecting soil productivity. (Oldeman et al. 1991). The causative agents of erosion are water and wind. Although wind erosion is presently of no major consequence, it can be serious as bare land increases due to the removal due to the removal of vegetation in the compound farming areas in the Sudan savannah zone.

On the other hand, large tracts of land have been destroyed by water erosion (Quansah et al. 1991). Studies by Asiamah (1984) on the extent of erosion reveal the land area susceptible to the various forms of erosion as 70,441 km^2 to slight to moderate sheet erosion, 103,248 km^2 to severe sheet and gully erosion and 54,712 km^2 to very severe sheet and gully erosion. These forms of erosion are common and severe where the vegetation has been disturbed in the savannah and forest zones, hilly areas and steep slopes. However, the most vulnerable zone is the northern savannah (Guinea and Sudan Savannah zones) which covers nearly 50% of Ghana with the Upper East Region being the most degraded area of the country. In this region, Adu (1973) reported a loss of 90 cm of soil by sheet and rill erosion. Some severely eroded lands had lost all the 120 cm thick solum above the un-weathered parent rock.

What is the nature of investments that need to be made to reduce erosion here?

Runoff plot studies on bare plots in the various ecological zones of Ghana (Table 7.10) show soil losses ranging from 187 t ha^{-1} in the semi-deciduous forest zone to 0.6 t ha^{-1} in the Coastal Savanna Zone (Bonsu 1979). The corresponding values of runoff of water? as a percentage of rainfall are 47 and 18. Climate change may also contribute to accelerated coastal erosion, to which Ghana is particularly vulnerable (ISSER/DFID/WB 2005).

On bare plots, it is related to slope?

A model of land degradation assessment in Ghana predicts that land degradation reduces agricultural income in Ghana by a total of US$4.2 billion over the period 2006—2015, which is approximately five percent of total agricultural GDP in these 10 years (Diao and Sarpong 2007).

Apart from soil erosion, most of the soils in the Forest-Savannah Transition, Guinea and Sudan Savannah Zones have predominantly clay loam textured surface horizons with clay pans appearing at shallow depths. How do they matter? Inappropriate tractorization in the early 1960s, without proper site selection with regard to soil characteristics resulted in topsoil physical degradation. Is the current tractorization okay?

An additional threat to the productivity of the soil resources of the country is the insidious formation of iron-pan (petroplinthite) within the soils. Over 96.000 km^2 of land in Ghana have been found to contain iron-pan, most of it covering the Guinea and Sudan Savannah and Transition Zones (FAO 1976). Iron-pan is the result of an irreversible hardening of plinthite which is a soft subsoil material.

7.2.2.2 Nutrient Depletion

Loss of nutrients, including organic matter, is the key contributor to chemical soil degradation. Nutrient depletion occurs primarily through crop removal in harvested products and residues, leaching, erosion and N volatilization. Stoorvogel and Smaling (1990) showed that nutrient losses through these depletion pathways are only partially compensated for by crop residues left on the field, manure and fertilizer application besides atmospheric inputs. Consequently the annual NPK balance for sub-Saharan Africa were negative with minus 22–26 kg N, 5.83–6.87 kg P_2O_5, and 18–23 kg K_2O ha^{-1} from 1983–2000.

In Ghana, annual depletion rate of 30 kg N, 3 kg P and 17 kg K h^{-1} were recorded for the period 1982–1984. The projected figures for year 2000 were 35 kg N, 4 kg P and 20 kg K ha^{-1}. The extent of nutrient depletion in Ghana is widespread in all the agro-ecological zones with nitrogen and phosphorus being the most deficient nutrients. These deficiencies are, however, more pronounced in the coastal, Guinea and sudanSavanna zones where organic matter content is low and the annual burning and removal of crop residues further prevent the build-up of organic matter. It has also been generally observed that the eroded sediments contain higher concentrations of organic matter and plant nutrients in available forms than the soil from which these were lost (Quansah et al. 2000).

The high losses of organic matter are of particular concern since nutrients applied to the soil in the form of mineral fertilizers are far less effective on soils with low organic matter content (Swift 1997). Moreover, organic matter is the main source of nitrogen, phosphorus and sulphur for plants in no-fertilizer peasant agriculture (Acquaye 1990). The loss of soil organic matter and soil fertility replenishment could therefore contribute significantly to marked increases in crop yield, food security and mitigate the effects of water stress.

7.2.2.3 Salinity

Salinity is a problem with most soils along the coast due to salt intrusion. These soils occur mostly within the coastal savannah zone. Acid sulphate clay soils and salt affected soils also occur oddly along the cost in the west where annual rainfall is about 2000 mm. Over 10,000 km^2 of these degraded soils have been mapped and classified as Arenosols, Solonetz and Solonchaks (Asiamah 1995). Apart from their high salt content and high acidity, most of these soils are heavy-textured, poorly grained with columnar structures (Asiamah 1999). What are the implications though?

7.2.2.4 Water Logging

In the Guinea and Sudan Savannah zones localized water logging is experienced every rainy season. This is mainly due to shallow soils, high rainfall intensities and poor surface drainage resulting from the general low relief of the terrain. Peak season floods are major cause of recurrent crop failures and food shortages. In the Coastal Savannah Zone, the low infiltration of Vertisols, the subdued relief and high rainfall intensities are responsible for periodic water logging which causes crop failure.

7.2.2.5 Land Tenure Arrangement

A key factor that determine the extent of nutrient mining in many areas of Ghana are prevailing land tenure arrangements and the lack of plant nutrients as mineral or organic fertilizers. The type of land tenure arrangements more often than not make farmers indifferent to the loss of future economic returns to land. For instance, the estimated technical efficiency for farms under sharecropping in the Guinea Sudan savannah zone is approximately 45.17% (Donkor and Owusu 2014). Sharecroppers have put enormous pressure on soil fertility to realize immediate high yields in order to pay land rents (Benneh 1997). Farmers in such situations discount the future at very high rates, thereby reducing the incentive for long-term investments in improved soil fertility.

Demographic pressures and land availability constraints have also contributed to the decline in soil fertility. With increasing populations, the traditional techniques for renewing soil fertility, such as slash-and-burn and long-term fallowing, are not as feasible as they once were. The need for subsistence production and income are such that land can no longer be taken out of production for substantial periods to allow for natural nutrient replenishment. Nor are animal manures and crop residues usually sufficient for replacing lost nutrients. In addition, particularly in the savannah zones, the promotion of rural non-agricultural development has increased the demand for crop residues as a source of fodder, fuel, and raw materials for artisanal activities, thereby limiting their availability as soil amendments.

Other traditional soil fertility management techniques also generally fall short of the nutrient requirements of today's intensive agricultural practices. Majority of farmers in Ghana generally do not have the resources to produce sufficient organic fertilizers to replace all the nutrients removed at harvest time. For example, in order to provide 150 kg of plant nutrients to fertilize one hectare of land, a farmer could apply either 200 kg of inorganic NPK fertilizer, or 10 to 15 metric tons of crop residue grown on 5–10 ha of land, or 18 metric tons of animal manure generated from crop residue grown on 10–15 ha of land (CSIR-SRI 2005).

7.2.2.6 Climatic Conditions

Harsh climatic conditions common to the Guinea and Interior savannahs also contribute to declining soil fertility conditions. Rapid water evaporation and inadequate and highly variable rainfall, for instance, deprive plants of the water necessary for growth. High atmospheric temperatures, strong light, and heat-retentive, sandy soils combine to make the local environment too hot for proper plant growth. Powerful, dry winds occasionally damage plants through both lodging (which causes plants to fall over and die before harvest) and evaporation.

Furthermore communal rights to graze land has led to serious overgrazing, which is reported to be the main cause of human induced degradation in the Guinea and Interior savannah zones.

7.2.2.7 Change in Forest Cover

Between 1990 and 2000, Ghana lost an average of 135,400 ha of forest per year. This amounts to an average annual deforestation rate of 1.82%. Between 2000 and 2005, the rate of forest change increased by 4.2% to 1.89% per annum. In total, between 1990 and 2005, Ghana lost 25.9% of its forest cover, or around 1,931,000 ha. Measuring the total rate of habitat conversion (defined as change in forest area plus change in woodland area minus net plantation expansion) for the 1990–2005 interval, Ghana lost 27.6% of its forest and woodland habitat. Deforestation exposes the land to all forms of degradation.

7.2.2.8 Indiscriminate Mining

Although information on land use statistics in Ghana does not clearly indicate the extent to which indiscriminate mining has degraded agricultural lands, reports indicate that more than 50% of agricultural lands in mining areas have been taken over by mining activities. For example in Tarkwa in the Western region, surface mining concessions have currently taken over 70% of the total land area. Studies by

Schueler et al. (2011), showed that surface mining has resulted in deforestation (58%), a substantial loss of farmland (45%) within mining concessions in the Western region, and widespread spill-over effects as relocated farmers expand farmland into forests.

7.3 Major Crops Grown in the Various Agro-ecological Zones

7.3.1 Crop Yield Gaps

Evidence suggests that considerably more plant nutrients are being removed and lost from cultivated fields than are being applied, with a consequent progressive impoverishment of the soils. Traditional, soil exhausting cultivation practices are still used extensively in all the ecological zones (Gerner et al. 1995). The difference between the quantities of plant nutrients applied and the quantities removed or lost show nutrient deficits for almost all the crops (FAO 2004). This represents a loss of potential yield and progressive soil impoverishment. According to the estimates, cassava and yams account for almost 20% of the cropped area but 37% of the nitrogen deficit. These crops remove large quantities of nutrients and their soils are prone to erosion during harvest.

The average yields of most of the crops are 20–60% below their achievable yields (Table 7.11), indicating that there is significant potential for improvement.

The average per hectare maize yields in Ghana for example are lower than the average for Africa, less than one-half of the world average, and less than one-third of the average for Southeast Asia (Fig. 7.1).

A major contributing factor to the low yields is poor soil fertility resulting from nutrient depletion and low input use. As a result of population increase, pressure on land has reduced to 8–15 years natural fallow period that is required to regenerate soil fertility after 1–3 years of cropping to only 2–3 years, further reducing soil fertility (FAO 2004a, b). Soils are not adequately protected by cover crops as crop rotation is hardly practiced, resulting in easily fragile soils that are easily eroded, a problem exacerbated by over farming.

Almost all the nutrient balances in Ghana show a deficit as more nutrients are removed by harvesting or lost to erosion than are applied as fertilizers (FAO 2004). This represents a loss of potential yield and progressive soil impoverishment. According to FAO estimates, cassava and yams account for almost 20% of the cropped area, but 37% of the nitrogen deficit. The highest depletion rates are in the southeast and the central west parts of Ghana, which correspond to the cassava area (FAO 2005).

Overall, Ghana is estimated to have annual nutrient losses around 60 kg/ha NPK, which is considered the highest in SSA (Henao and Baanante 1999; Stoorvogel et al. 1993). Several studies have suggested that large increases in fertilizer usage

Table 7.11 Average yields of some selected crops and potentials yields gaps

Crop	Average yeilds (mt/ha)	Potential yeilds (mt/ha)	Yield gap (mt/ha)	Yield gap (% achievable)	Expected increase to meet target (%)
Maize	1.5	2.5	1	40	67
Cassava	12.7	28	15.3	55	120
Rice (paddy)	2	3.5	1.5	43	75
Yams	12.4	20	7.6	38	61
Cowpeas	0.9	1.3	0.4	31	44
Millet	0.8	1.5	0.7	47	88
Sorghum	0.9	1.5	0.6	40	67
Cocoyams	6.5	8	1.5	19	23
Plantains	8.1	10	1.9	19	23
Sweet potatoes	8	18	10	56	125
Groundnuts	0.8	1	0.2	20	25
Soybeans	0.8	1	0.2	20	25
Cocoa	0.4	1	0.6	60	150
Pawpaw	26	40	14	35	54
Pineapple	65	100	35	35	54
Tomato (rainfed)	25	35	10	29	40
Tomato (irrigated)	30	65	35	54	117
Garden eggs	8	15	7	47	88
Pepper	10.3	15	4.7	31	46

Source: SRID, METASIP (September 2010) and Breisinger et al.

are necessary to correct the massive nutrient losses of much of the arable land in SSA (Morris et al. 2007; Heisey and Mwangi 1997; Wallace and Knausenberger 1997). Ironically as of 2010, fertilizer use in Ghana was 8 kg/ha, well below the average in SSA (FAOstat 2014).

7.3.2 *Fertilizer Use in Ghana*

Numerous studies show that substantial agricultural productivity gains can be achieved in SSA in increasing the use of fertilizer and the efficiency of its utilization (Eicher 1994; Ersado et al. 2004; Tomich et al. 1995; Maiangwa et al. 2007). Experiences outside Africa also highlight fertilizer's key role in boosting agricultural productivity. Fertilizer was an integral part of the technological trinity – improved seed, irrigation, and fertilizer – responsible for bringing about the Green

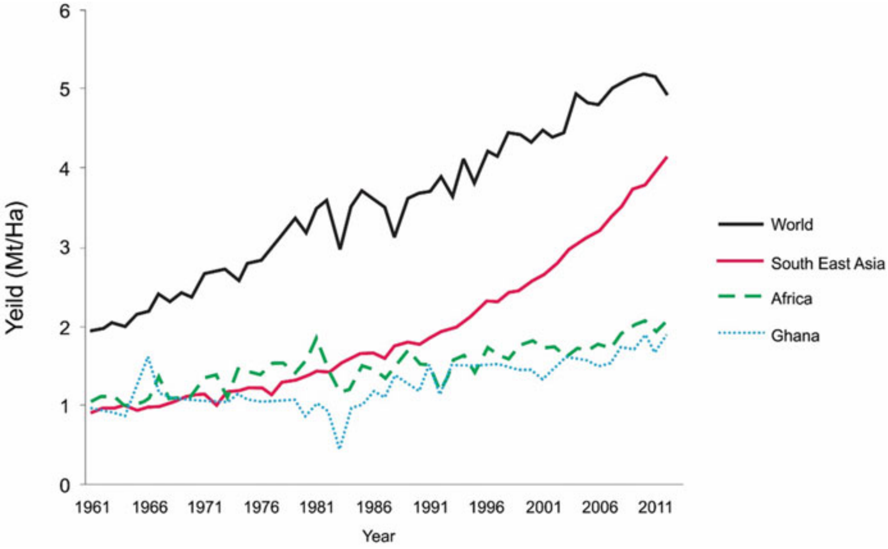


Fig. 7.1 Average maize yields (Source FAOStat 2014)

Revolution in Latin America and Asia, and it contributed as much as 50% of crop yield growth in the regions (Bumb and Baanante 1996; Dufluo et al. 2003; Kikuchi and Aluwihare 1990; Mujeri et al. 2012; Viyas 1983).

Fertilizer consumption in SSA is the lowest in the world, making up only 2% of the 2002 world supply and expected to rise to only 3% by 2011/12 (Camara and Heinemann 2006). In recent years SSA's fertilizer consumption has fluctuated and ultimately decreased to 1,041,000 MT of nutrients in 2007, as compared with 1,113,000 MT in 2002 (Fig. 7.3). Nitrogen has accounted for more than half of the total consumption in the region. From 2002 to 2007, nitrogen accounted for 53% of the almost 7 million MT of nutrients consumed in SSA, phosphate accounted for 29%, and potash accounted for the remaining 18% (Hernandez and Torero 2011). Despite the relatively dismal aggregate trends in fertilizer use in SSA, great variability in fertilizer use has been observed within the region.

Historically, Ghana has seen some fluctuations in fertilizer usage, but the rates have always remained relatively low (FAO 2005). The average Nitrogen and Phosphate fertilizer application rates per hectare in Africa and Ghana indicates that, while the gap between the rates has decreased in recent years, the average fertilizer application rates in Ghana are still well below the average of Africa overall (Fig. 7.2).

Although the importance of inorganic fertilizers is clearly emphasized in national development plans, its adoption in Ghana is very low. The average application rate is less than 8 kg/ha, which is considerably lower than in other countries like Malawi and Kenya, where application rates are 22 and 32 kg/ha, respectively (Fuentes et al. 2012). Fertilizer application rates are highest for cash crops such as cocoa, cotton, palm oil and vegetables. Application rates for maize

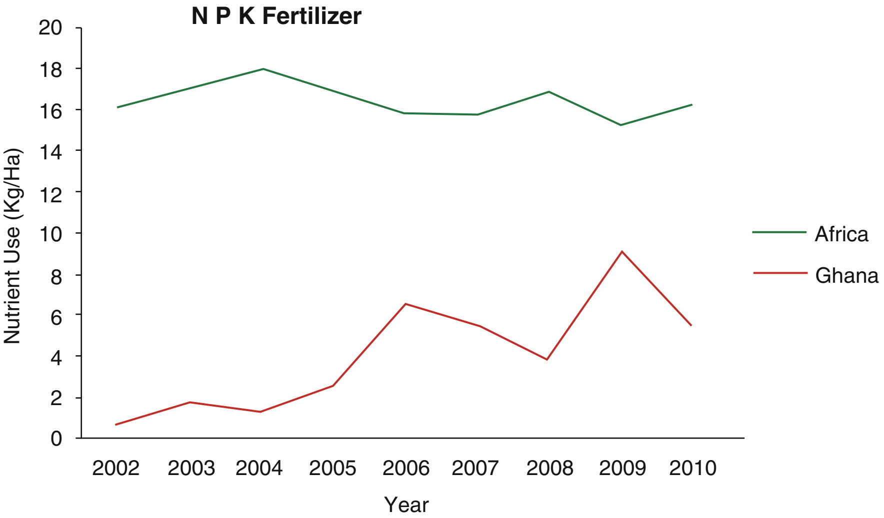


Fig. 7.2 Average fertilizer nutrient application (Source: FAOStat 2014)

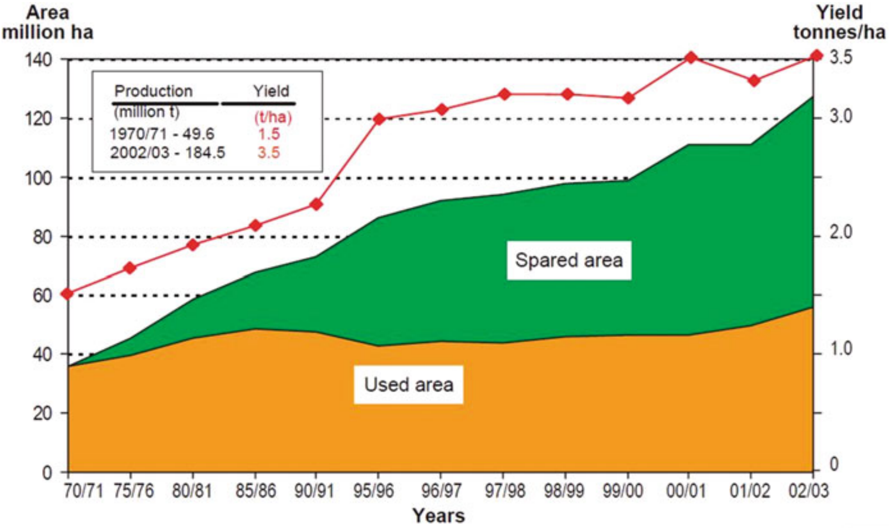


Fig. 7.3 Crop production, yields and land spared from deforestation, Brazil, 1970–2002 (Source: FAO Fertilizer and Plant Nutrition Bulletin 17, 2006)

are in the intermediate range, while application rates for crops such as cassava, millet, sorghum and yams are negligible (FAO 2005). The number of households using fertilizer by 2011 was 31% on average, although there is some variation across the country (Quiñones and Diao 2011). Approximately 10% of smallholders

Table 7.12 Observed yield paramaters of Obaatampa Maize grown at Kpalesawgu in Guinea Savanna zone of Ghana

Treatments (kg/ha N-P_2O_5-K_2O)	Yield (kg/ha)
0-0-0	231
40-60-60	1208
80-60-60	2503
120-6060	3789
150-60-60	3522
120-0-60	1258
120-45-60	3239
120-90-60	3831
120-60-0	3314
120-60-45	3772
120-60-90	3578
Probability Function	<0.01
Least Significant Difference	99.3
Coefficient of Variation	0.5

Adapted from Atakora et al. (2014)

with less than 1.0 ha use fertilizer, compared with over 20% of those with more than 5.0 ha (GoG 2010). Thus agricultural growth in Ghana has been mainly due to land area expansion as opposed to yield increases.

Similar to Ghana, Brazil is characterized by a large diversity of soil types, however the increased use of mineral fertilizers in Brazil has played an important role in the development of agricultural productivity and environmental preservation in the past 30 years in Brazil (Fig. 7.3). An additional cropped area equivalent to 77 million ha of cleared forest would have been necessary if the current total production were to be obtained with the yield average of 1970.

7.3.3 Response to Fertilizer Application

Varied results on crop response to fertilizer application are found in the literature. This is to be expected due to lack of uniformity over a wide range of ecological conditions, especially soil types, under which the various crops are cultivated. Generally on responsive soils, where applied fertilizer nutrients overcome crop nutrient limitations, substantial responses to fertilizers can be expected. For instance maize yield increase over the control due to NPK fertilizer application from 6 sites in the forest and transition zones and average over 3 years was 130%, when the soil was amended with poultry manure (SRI 2008).The response of hybrid maize O *baatanp*to NPK application in the Guinea Savanna (Kpalesawgu) zone of Ghana is presented in Table 7.12.

The highest grain yield was obtained when 120-90-60 Kg/ha N-P_2O_5-K_2O was applied.

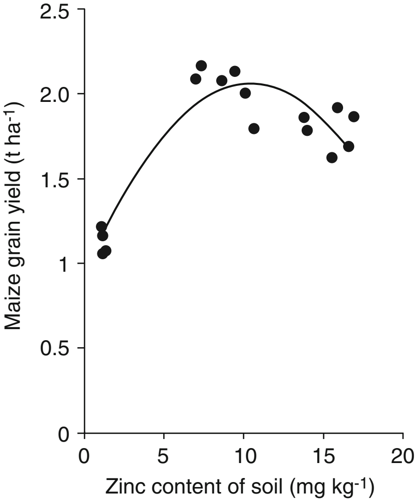


Fig. 7.4 Influence of soil Zn content on Maize Grain Yield (Source: Adapted from Abunyewa and Mercer-Quarshie 2004)

The degree of insignificance difference between 40-60-60 and 1200-60 NPK Kg/ha applied indicates that P is a limiting nutrient. There was also no significant difference between grain yield when 120-45-6- and 120-60-0 NPK was applied.

Despite these positive improvement to fertilizer application studies have shown that there are great on farm soil fertility gradients and yields are bound to vary greatly even on the same production unit.

The inorganic fertilizer available to farmers contains mainly N and P with/without K. Though farmers grow various genetically improved crop varieties with high yield potentials, yields have been observed to be low. For instance in maize yields in the Guinea and Interior savannahs of Ghana, have been found to rarely exceed 1 t ha^{-1} in farmer's field. The observed low maize grain yield in spite of the application of NPK compound fertilizer indicates possible deficiencies of other important nutrients.

The highly weathered and sandy-textured soils of these zones tend to be limiting in micronutrients. Thus the application of Zn improved maize grain yield by 100% (Fig. 7.4.) stressing the need for balanced fertilization.

The response of sweet potato to fertilizer application in the Forest Transition and Savanna Zones is given shown in Fig. 7.5. Compared with the control, sweet potato responded positively to fertilizer application in two the locations. The yield of sweet potato is significantly depressed if potassium is missing. However, eliminating phosphorus does not affect the yield.

The yield is also depressed slightly when nitrogen is missing. Balanced fertilization gives large tubers while the number of tubers harvested decreases (Table 7.13) (Fig. 7.6).

Phosphorus deficiency is acute in the majority of soils in Ghana. Local farmers on the other hand use very low P fertilizers partly because of the high cost. The use of locally available phosphate rock (PR) could be an alternative to imported P

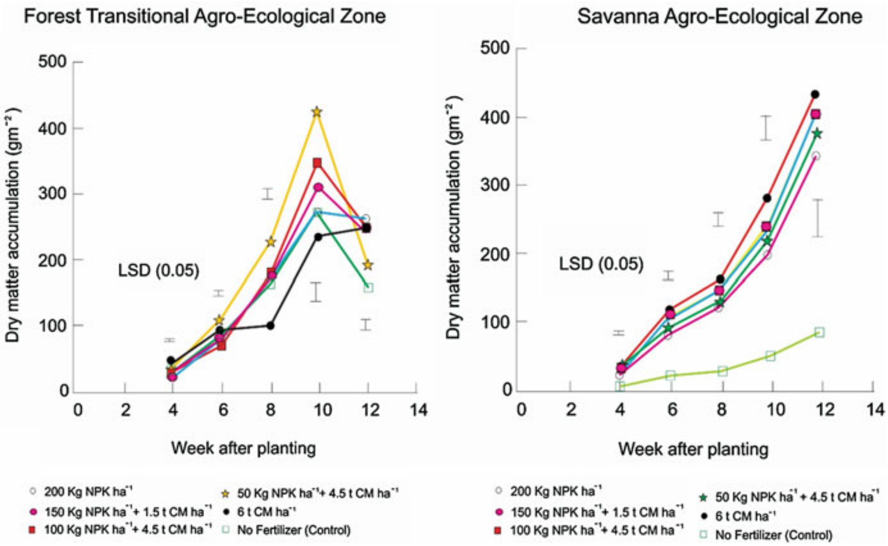


Fig. 7.5 Response of sweet potato to fertilizer application in two Agro-ecological Zones (Source: Adapted from Yeng et al. 2012)

Table 7.13 Sweet potato: response to nutrient balances

Treatment N-P-K (kg/ha)	Yield of Tubers (t/ha)	Average weight per tuber (g)	Tuber per ha (thousands)
0-30-30	11.00	136.00	83.50
30-0-30	12.60	130.80	96.00
30-30-0	8.75	132.70	68.00
30-30-30	12.30	163.70	76.00

Source: Adapted from 2003 Annual Report, CSIR-SRI

fertilizers. For example, Bationo et al. (1987) showed that direct application of local PR may be more economical than imported water-soluble P fertilizers. While all crops need an adequate supply of Phosphorus, legumes are particularly responsive and large inputs from nitrogen fixation are only possible when P deficiencies are corrected. Large increases in cowpea and other legumes yield are observed in most soils when P fertilizer is applied. The response to P fertilization is insignificant when the initial fertility status of the soil is low (Fig. 7.7).

The deficiency of P is found to be as important as or more important than that of N for crops such as upland rice grown in the humid forest or savanna zones in West Africa (Sahrawat et al. 2000, 2001). The direct application of PR to acidic pH soils (Ultisols and Oxisols) in the humid forest zone of SSA holds greater potential for boosting production of upland rice cultivars compared to production of rice in the dry regions (Sahrawat et al. 2001).

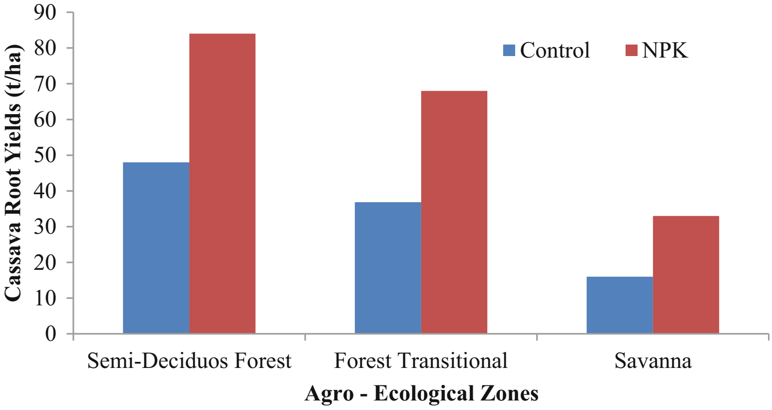
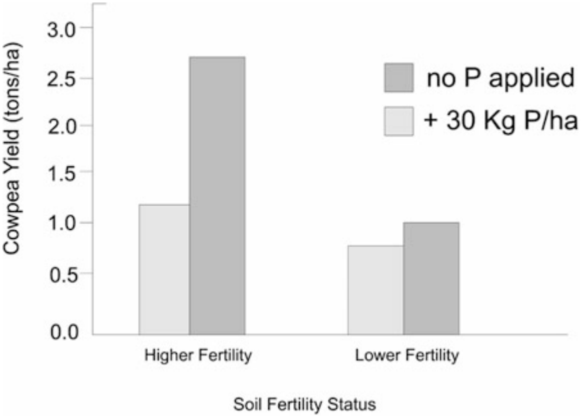


Fig. 7.6 Root Yield of Cassava to NPK (60-40-40) application (Source: Adapted from 2007 Annual Report, CSIR-SRI)

Fig. 7.7 Response of Cowpea to P Application (Adapted from 2010 Annual Report, CSIR-SRI)



There continues to be low crop response to fertilizer application in farmers' fields mainly because of poor fertilizer management by farmers; fertilizer unavailability at the time it is needed; lack of complementary inputs, such as improved seeds and irrigation (Bationo et al. 2006). There has also been low profitability from fertilizer use mainly due to the low response, high fertilizer prices and low and unstable product prices.

More fertilizer yield response and profitability studies are therefore needed for a range of crops in Ghana. Profitability ratios under a range of input and output cost scenarios should be determined across the country so that farmers can know beforehand what levels of fertilizer application will be profitable for them to use on a particular type of crop.

7.3.4 Profitability of Fertilizer Usage

The demand for a particular variety/brand of fertilizer (like nitrogen) is derived demand, price elastic and influenced by the price of other varieties/brands of fertilizer (Acheampong and Dicks 2012). The price and/or availability of other inputs that complement and enhance fertilizer productivity – for example, hybrid seed and irrigation, also play an important role in farmer's decision to use fertilizer. Similarly, the price and/or availability of other inputs that substitute a variety of fertilizer as well influence its use (Acheampong and Dicks 2012).

Langyintuo and Mekuria (2005) categorized factors that influence farmers' decisions to use agricultural improved inputs as: farmer characteristics, institutional factors and characteristics of the input. Farmer characteristics among others include; sex, age, education, and household size while institutional factors include farm size, membership to association, access to information, access to credit, and access to infrastructure such as roads or storage. Characteristics of the factor input relate to the subjective attributes of the input as perceived by the farmer (Adesina and Zinnah 1993).

The wedge between the high price of fertilizer on the one hand and low price of crops on the other, especially for farmers in landlocked countries in SSA is one of the major factors that make them reluctant to use the input. Morris et al. (2007) observe that demand for fertilizer is often weak in Africa because incentives to use fertilizer are undermined by the low level and high variability of crop yields on the one hand and the high level of fertilizer prices relative to crop prices on the other. Smaling et al. (2006) indicate for example that farmers in Africa require 6–11 kg of grain to purchase one kg of nitrogenous fertilizer compared with about 2–3 kg of grain in Asia. High fertilizer prices in SSA are mostly attributed to high transaction costs of fertilizer trade arising from high transportation costs, high interest rates and low volume of purchases (Gregory and Bumb 2006). Lack of market Lack of market information about the availability and cost of fertilizer and the inability of many farmers to raise the resources needed to purchase fertilizer in bulk is cited among other factors that make farmers pay more for fertilizer (Morris et al. 2007). Low farm-gate prices for crops on the other hand is mainly influenced by poor road infrastructure and lack of storage facilities as well as lack of market information (Torero and Chowdhury 2004; Morris et al. 2007).

According to Morris et al. (2007), even if farmers believe that fertilizer is profitable, they may be unable to purchase it if lack cash and/or cannot obtain credit. In agricultural households, the main sources of cash include earnings from salary/wage employment, sell of livestock, and trade. Besides, farm-household size and composition – which has close links with labour supply as well as the income status of the household head, has both positive and negative implications on adoption of inputs. In case of labour intensive inputs such as production and use of organic fertilizer, availability of labour with minimum knowledge can encourage its use even in poor households. On the other hand, if large households are disproportionately poor, then lower use of relatively expensive inputs such inorganic fertilizer is expected in households with large families. Information about the

Table 7.14 Partial budget for eight fertilizer treatments on maize in 2011

Treatment	Treatment for 2011 – Across locations							
	1	2	3	4	5	6	7	8
Mean yield of maize (kg ha^{-1})	2397	3772	4114	4203	4311	4277	4761	4894
Adjusted yield (kg/ha^{-1})	2157.3	3394.8	3702.6	3782.7	3879.9	3849.3	4284.9	4404.6
Gross field benefits (GH ¢/ha)	1078.6	1697.4	1851.3	1891.9	1939.95	1924.6	2142.4	2202.3
Cost of NPK (15-15-15)	–	51	51	51	–	–	–	–
Cost of sulphate of ammonia	–	35	–	–	–	–	–	–
Cost of Sulfan fertilizer	–	–	35	–	–	–	–	–
Cost of Urea fertilizer	–	–	–	46	–	–	–	–
Cost of Actyva fertilizer	–	–	–	–	51	51	51	51
Cost of Winner fertilizer	–	–	–	–	–	–	–	52
Cost of fertilizer application	–	50	50	50	50	75	75	75
Total cost that vary (GH ¢/ha)	–	136	136	147	101	126	126	178
Net benefits (GH ¢/ha)	1078.6	1561.4	1715.3	1744.35	1838.95	1798.6	2016.4	2024.3

availability and cost of fertilizer and the inability of many farmers to raise the resources needed to purchase fertilizer in bulk is cited among other factors that make farmers pay more for fertilizer (Morris et al. 2007).

The appropriate dosages for application of inorganic fertilizer formulations on maize yield and profitability was assessed in the semi deciduous and transition zones of Ghana. According to Berchie et al. 2013, the application of Actyva (125 kg/ha) at planting plus Winner (125 kg/ha) at 2 WAP plus Actyva (250 kg/ha) at 4 WAP out-yielded the recommended fertilizer rate by 30% and the control by 104% in 2011 and also produced the highest grain yield across locations in both 2011 and 2012. The partial budget for the various treatments (Tables 7.14 and 7.15) showed that the net benefit for no fertilizer application (GH ¢ 1078.6) was lower than all the treatments.

7.3.5 *Importance of Agronomic Efficiency*

Returns can be increased with effective use. Nutrient recoveries of applied fertilizer by crops under farmers' practices are distressingly low. Only about 10–15% of the P

Table 7.15 Partial budget for eight fertilizer treatments on maize in 2012

Treatment	Treatment for 2012-Across locations							
	1	2	3	4	5	6	7	8
Mean yield of maize (kg ha^{-1})	4027	3978	3761	4230	4415	4588	4113	4769
Adjusted yield (kg/ha $^{-1}$)	3624.3	3580.2	3384.9	3807	3973.5	4129.3	3701.7	4292.1
Gross field benefits (GH ¢/ha)	2174.58	2150.94	2030.9	2284.2	2384.1	2477.58	2221.02	2575.26
Cost of NPK (15-15-15)	–	51	51	–	–	–	–	51
Cost of sulphate of ammonia	–	–	–	–	–	–	–	35
Cost of Sulfan fertilizer	–	35	–	–	–	–	–	–
Cost of Urea fertilizer	–	–	46	–	–	–	–	–
Cost of Actyva fertilizer	–	–	–	51	51	51	51	–
Cost of Winner fertilizer	–	–	–	–	–	–	52	–
Cost of fertilizer	–	50	50	25	25	25	50	50
Total Cost that vary (GH ¢/ha)	–	136	147	76	76	76	153	136
Net benefits (GH ¢/ha)	2174.58	2014.94	1883.9	2208.2	2308.1	2401.58	2068.02	2439.26

Adapted from Berchie et al. (2013)

and 10–20% of the N and K applied through fertilizer is assimilated by crops. This ineffective use of fertilizer in effect discourages investment in fertilizer by poor African farmers (Africa Fertilizer Summit 2006). Low assimilation efficiencies are common as a result of several factors. Crops require nutrients in different quantities and proportions. According to the Law of Minimum (Russel 1973), deficiency in one nutrient results in reduced plant growth and less ability to make use of all other nutrients. Most fertilizers only address the primary nutrient requirements of crops (N, P, K). In this regard soil reserves of non-limiting nutrients decline with intensifying cultivation, limiting the use of efficiency of these fertilizers that do not contain them (Giller et al. 1998; Vanlauwe et al. 2006). However applying the Law of Optimum, evidence suggests that the lack of one nutrient influences the

Table 7.16 Nitrogen Use Efficiency (NUE), grain yield, and yield components of Sorghum as affected by N, P, and K Fertilizer levels

Treatment	100 kernel Weight (grams)	Kernel m^{-2}	Grain Yield (kg ha^{-1})	NUE (kg grain kg N^{-1})
P_2O_5 level (kg ha^{-1})				
0	2.05a	6517a	1930a	11.3a
40	2.13a	7018a	2092b	11.9a
K_2O level (kg ha^{-1})				
0	2.08a	6765a	1992a	11.4a
40	2.10a	6830a	2029a	11.8a
N level (kg ha^{-1})				
0	2.18	4342	1397	
40	2.06	6928	2048	16.3
80	2.07	7833	2242	10.6
120	2.07	8088	2356	7.9
N linear	NS	–	–	–
N quadratic	NS	–	–	NS
CV (%)	11	22	14	35

Adapted from Buah et al. (2012)

efficiency of uptake of another one at even non limiting levels. In this way stressed crops are limited in their ability to make efficient use of applied nutrients. Drought stress leads to impaired root development. Soil characteristics such as soil crusting, impermeable soil layers, extreme pH levels and Al toxicity negatively affect plant root development and nutrient uptake. Ineffective management of inputs leads to nutrients losses and inefficient utilization by crops. Fertilizer application needs to be applied and timed at appropriate rates in accordance with crop nutrient requirements and tailored to environmental conditions.

The agronomic and economic benefits of applying nitrogen (N), phosphorus (P), and potassium (K) fertilizers to sorghum in the Guinea savannah zone of Ghana has indicated that fertilizer N, P, and K did not show significant inter- actions for any parameter. Across years, added K did not influence grain yield and yield components. However, P increased yield by 14%, and N affected yield in a quadratic manner. The application of 40, 80, and 120 kg N ha^{-1} resulted in yield increases of 47%, 60% and 69% over farmers' practice (0 kg N ha^{-1}), respectively. Economic analysis revealed that two N and P combinations, i.e., 40:0 and 40:17.2 kg ha^{-1}, were economically superior and stable within a price variability range of 20%. Thus, farmers in the Guinea savanna agro-ecology in Ghana can get better returns on the money invested in fertilizer for producing improved sorghum than with their traditional practice of no fertilizer input. (Buah et al. 2012)

Nitrogen-Use Efficiency (NUE) calculated as a ratio of grain yield to amount of N applied was not affected by added P and K when averaged across N levels (Table 7.16). However, NUE decreased as a linear function of N rate when averaged across P and K levels. Sorghum had highest NUE (16.3 kg grain kg^{-1} N)

Table 7.17 Nutrient content of cattle and poultry manure

Source of Manure	Agro-Ecological Zone	Nutrient content (mg/g)		
		N	P_2O_5	K_2O
Cattle	Sudan Savannah	18.5	10.5	3.0
	Guinea Savannah	13.2	7.3	6.1
	Coastal	14.2	7.2	8.5
Poultry	Forest	29.58	20.87	7.02

Source: Adapted from Fening et al. (2005a, b)

at 40 kg N ha^{-1}. The use of 80 kg N ha^{-1}or 120 kg N ha^{-1}, however, did not result in a corresponding increase in NUE across years. On average, the 120 kg N ha^{-1} treatment resulted in the lowest NUE value of 7.9 kg grain kg^{-1} N. Economic analysis (partial budgets) for fertilizer N and P levels showed that all the treatments had positive gross benefits when averaged across years and K levels. The net benefits ranged from US$366 to US$542. Fertilizer application gave gross benefits and net benefits that were greater than those of no fertilizer treatment (farmers' practice) (Buah et al. 2012).

7.3.6 Response of Crops to Organic Manure

The two most important types of manure being used by farmers in Ghana are cattle and poultry. Cattle manure is popularly used in the savannah ecosystems where cattle production is predominant. Poultry manure on the other hand is commonly used in the forest zones where there are large commercial poultry farms. Cattle manure are usually obtained either from kraals where the animals are housed or from the animal droppings in the field. Table 7.17 gives the nutrient qualities of some sampled cattle and poultry manure.

In the Interior, Sudan Savannah and Forest transitional zones, cattle manure is commonly applied to crops, including maize, millet, sorghum, cowpea, cassava. The use of poultry manure is more common to the Coastal savannah and Forest zones.

7.3.7 Response to Inorganic and Organic Manure Combination

The need for the application of both organic and inorganic fertilizer to reserve the declining trend in soil fertility has emerged in recent years. While fertilizers supply plant nutrients, organic manure is a precursor of soil organic matter, which

Table 7.18 Cassava root yield and partial budget analysis in response to combined application of organic and inorganic fertilizer

Treatment	Root weight t/ha		Partial budget analyses (000 Cedis)		
	2002	2003	Gross farm gate benefits	Total variable input cost	Net benefit
Control	55b	43b	4400	2130	2270
$N_{30}P_{20}K_{20}$	87a	74a	6960	2900	3950
$N_{60}P_{40}K_{40}$	89a	92a	7120	3590	3530
PM 2.5 t/ha	89a	77a	7120	2610	4510
PM 5.0 t/ha	96a	85a	7680	2890	4790
$N_{30}P_{20}K_{20}$ + PM 2.5 t/ha	113a	96a	9040	3340	5700
LSD ($P = 0.05$)	31	24			

At the time of this work US\$1 = 8200 Cedis. Source: Fening et al. (2005a, b)

maintains the physical and physic-chemical components contributing to soil fertility such as cation exchange capacity (CEC) and soil structure. The major reason for advocating the use of organic manure and inorganic fertilizer in combination is that either one of them may not be available or affordable in sufficient quantities. One other salient aspect of simultaneous application of the two nutrient sources is the potential for positive interactions between both inputs leading to added benefits in the form of extra grain yield or improved soil fertility and reduced losses of nutrients. Table 7.18 demonstrates the benefits of combined application of organic and inorganic fertilization for sustainable cassava production.

7.4 Soil Fertility Management Practices

A range of soil management technologies that have been adopted by farmers across the agro- ecological zones has been documented (Table 7.19). Differences that occur between zones can be explained from differences in farm type and farming intensity as well as from the cropping system and its biophysical conditions. There are differences in farm structure and land ownership, historical development of agricultural production, protection of the environment and landscape, and main recommendations by agricultural extension services that may cause differences between zones and management practices. Available evidence shows that these technologies increase agricultural productivity in the environments in which they have been adopted and provided farmers with some significant yields. But it is also known that what may work in one site, may not work in another due to differences in soil types, acidity levels, organic matter content, chemical composition of soils, rainfall, slope of land and other factors.

Table 7.19 Soil fertility management practices in Ghana

Agro-ecological zone	Soil management practices
Coastal savanna	Strip cropping, Crop rotation, Organic and Inorganic Fertilization
High rainforest	Closed Canopy cropping, Mixed cropping, Liming, Soil erosion measures, Drainage control and Organic and Inorganic Fertilization
Semi-deciduous forest	Mixed cropping, Agroforestry, Organic and Inorganic Fertilization, Contour cultivation, Cover cropping, Flood and Drainage control, Mulching, Strip cropping
Forest savanna transition	Mixed cropping, Agroforestry, Organic and Inorganic Fertilization, Cover cropping, Mulching, Strip cropping rotation
Guinea savanna	Mulching, Stone terracing, Strip cropping, Crop rotation, Organic and Inorganic Fertilization, Contour ploughing, Residue retaining, Drainage control, Liming

Source: Adapted from Ghana National Soil Fertility Management Action Plan 1998

7.4.1 Proven Soil Fertility Technologies That Can Be Scaled Up

Small holder farming systems in Ghana occur within diverse biophysical and socio – economic environment. The farmers therefore develop different livelihood strategies driven by opportunities and constraints encountered in such environments. Within ecological zones, and localities within the zones farmers differ in resource endowment, production orientation education, past experience, objectives of production and management skills and attitudes towards risks. Studies on farm typologies have shown the fundamental differences between farm categories, with about 3 typologies that often represent the differences in resource endowment. (1) - Resource-endowed farmers who are usually large scale farmers have ready access to large quantities of manure and mineral fertilizers, which contribute to higher soil fertility and crop productivity on their farms. (2) Resource-constrained farmers who use little or no manure and mineral fertilizers, and have limited capacity to invest in labour-demanding soil fertility management technologies. (3) Sharecrop holders who discount the future fertility of the soil, thereby reducing the incentive for long-term investments in improved soil fertility management. Recognition of these variables is the first step with regard to the adoption of new technologies. An array of nutrient management strategies tailored to specific agro-ecological zones rather than blanket recommendations across diverse zones that have been developed for sustainable crop production intensification include the following:

7.4.1.1 Cassava – Cowpea Strip Intercropping/Rotation

The technology involves simultaneous growing of cassava and cowpea in strips wide enough to allow independent cultivation but, at the same time, sufficiently narrow to induce crop interactions.

Advantages

- Improves yield of component crops
- Increases farmers monetary returns
- Improves soil fertility
- Facilitates independent crop management
- Offers greater yield stability
- Reduces risk of total crop loss
- Offers better land use efficiency

Studies conducted in the transitional and forest ecological zones using this technology improved yields of component crops by over 50% (Fening et al. 2009).

7.4.1.2 Conservation Agriculture

Water is a key constraint to crop production in the Sudan and Guinea Savanna zones of Ghana. Large areas within the region receive less than 800 mm rain annually in a normal year and are prone to drought periods within the cropping season. Conservation agriculture offers possibilities for better water management and yield enhancement. Conservation agriculture involves a number of approaches for reducing tillage, which results in higher retention of soil organic matter and improved physical properties of soil, such as water holding capacity, aggregation and infiltration. In addition to minimum or zero tillage, conservation agriculture involves early land preparation and timely planting, legume rotations, micro-water basins, point seeding and fertilizer application, and covering the soil with biomass (crop and farm residues).

Although the practice is not yet widespread in SSA and many of its technologies are not available or well-suited to small-scale farmers, incorporation of many of the principles fundamental to Conservation Agriculture can assist in ISFM. Currently CA is practice to a lesser extent in Ghana mainly in the Guinea and Sudan savannah zones (Derpsch 2008).

7.4.1.3 SAWA Technology

The concept and the term “Sawa” refers to man-made improved rice fields with demarcated, levelled, bunded and puddle rice fields with water inlets and outlets which can be connected to various irrigation facilities such as irrigation canals, ponds, springs and pumps. The SAWA system of rice production ensures proper management of the rice environment and improves the fertility status of the soil, resulting in efficient and higher grain production with higher returns. Under the SAWA technology rice yield increased from less than 1 t/ha to over 6 t/ha under farmers’ conditions in the inland valleys of Ashanti and Brong Ahafo regions of Ghana (Buri et al. 2007). Increase in rice production under the traditional system has mainly been due to increased area put to rice as against SAWA which increase yield per unit area.

7.4.1.4 Combined NPK and Manure

The benefits of the combined application of manure and NPK has been demonstrated extensively in maize, yam and cassava. In cassava for instance a monetary return of over 50% has been achieved with half the rate of NPK and poultry manure in the forest transition zone. (Fening et al. 2005a, b).

7.4.1.5 Green Manures

The use of cattle is very limiting in the semi-deciduous zone where livestock is not fully integrated in the farming system. Other organic resources such as high biomass producing plants could therefore be used as alternatives to address declining soil fertility. The use of plant biomass for soil fertility replenishment requires the identification of species found in the farm vicinity to reduce labour cost. Such plant species should have the ability to increase P availability and produce a large pool of mineral N before the period of rapid N uptake by a crop. The use of *Chromolaena odorata*, *Crotalaria juncea* and *Panicum maximum* and their combination with NPK for improving soil fertility and maize yield has been investigated in the semi-deciduous zone of Ghana. The plant materials plus $N_{45}P_{30}K_{60}$ provided nutrients that were sufficient to increase maize yields by over 85% relative to the control for two consecutive seasons. Maize grain yield was not influenced by the quantity of plant materials applied. (Fening et al. 2009).

7.5 Potential of BNF for Improving Soil Fertility

Nitrogen is the most limiting nutrient element to crop production in Ghana. Nitrogen deficiency results from its continual removal from the soil pool by processes such as volatilization, leaching and most importantly, removal from harvested crops and residues from the soil. The nitrogen reserve of agricultural soils must therefore be replaced regularly in order to maintain an adequate level of production. The replacement of nitrogen is generally accomplished by the addition of inorganic fertilizers or by biological nitrogen fixation (BNF). While there is a wide range of organisms and microbial–plant associations that are capable of fixing atmospheric nitrogen, the symbiotic relationship between rhizobia and legumes is responsible for contributing the largest amounts of fixed nitrogen to agriculture. In contrast to expensive chemical N fertilizers, BNF is often a more attractive and practicable alternative. Maximal rates of BNF recorded in the tropics reach an astonishing 5 Kg N/ha/day (Giller 2001). More than 250 Kg N/ha of fixed N has been measured in soybean in southern Africa with associated grain yield of 4 t/ha. Thus when effective BNF can meet the goals of the Abuja Summit in the fields where legumes are grown.

Recent analysis of the Ghanaian farming system like others in the sub region indicates that less than 5% of farm lands are often planted to legumes. This is often due to relatively poor market prices for legume grains. However even at the current rates of BNF, which are substantially low a modest increase of the farm are planted with legumes to 105 will automatically double the amount of N input into framing systems. Attention should be given to improving the BNF of useful legumes in Ghana such as cowpea, soybean, common bean, groundnut and pigeon pea.

7.5.1 Use of Inoculants for Improving Soil Fertility

A common approach to improve BNF and legume productivity has been the reliance on superior or very effective exotic rhizobia strains as inoculants. This approach has, however, failed to achieve the desired responses in Ghana. The failure has largely been attributed to the poor nodulation competitiveness of the introduced rhizobia. When introduced, the inoculant rhizobia must adapt to the prevailing soil conditions, multiply in the soil and host rhizosphere and compete with the indigenous often ineffective rhizobia population for infection sites. But unfortunately, the inoculants often fail to occupy a significant proportion of the nodules. A way of improving the success of inoculants can be to use native strains that are effective as well as competitive for nodulation as inoculants. This is currently being investigated under the N2Africa project at CSIR-Savanna Agriculture Research Institute (SARI).

Cowpea (Vigna inguiculata) is an important food legume that features prominently in many farming systems in all the ecological zones of Ghana (Fening and Danso 2002). However, there is great variability in the numbers of bradyrhizobia that nodulate cowpea in Ghanaian soils (Fening and Danso 2002). While no bradyrhizobial were detected in 20% of the soils, at least 60% of the soils contained more than 1×10^3 bradyrhizorbial cells gram per soils. Twenty percent (20%) of the remaining soils contained between 100 and 1000 cells gram per soil (Fig. 7.8).

The effectiveness of the isolates in fixing nitrogen in cowpea is shown in Table 7.20. Generally, distribution of the isolates in the ecozones followed a normal distribution trend with the majority being moderately effective (Fening and Danso 2002).

The relative effectiveness of the 10 most effective isolates against the standard strain TAL 169 indicated that 7 of the isolates possessed symbiotic effectiveness superior to the standard strain, with 4 of these differing significantly from the standard strain (Fig. 7.9).

It is also estimated that in Ghana the benefit of nodulated cowpea to soil nitrogen supply is 60 kg N ha^{-1} when residues from the crop are incorporated into the soil (Dakora et al. 1987).

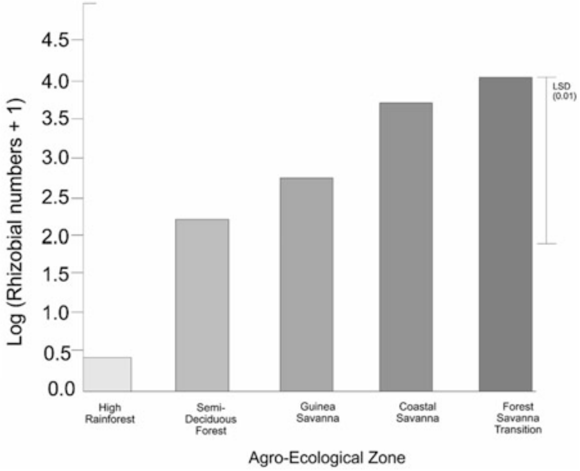


Fig. 7.8 Most Probable Number Estimates of Bradyrhizobia in the Different Agro-ecological Zones. (Source: Fening et al. 2002)

Table 7.20 The effect of agro-ecological zones on the relative effectiveness of Native Cowpea Bradyrhizobia Isolates

	Indices of Effectiveness (%)			
Agro-Ecological Zone	n	Highly effective	Moderately effective	Ineffective
Coastal savanna	20	20.8	75	4.1
High rainforest	20	75	25	0
Semi-deciduous forest	20	33.3	58.3	8.3
Forest savanna transition	20	25	66.7	8.2
Guinea savanna	20	16.7	79.2	4.1

Source: Fening et al. (2002)

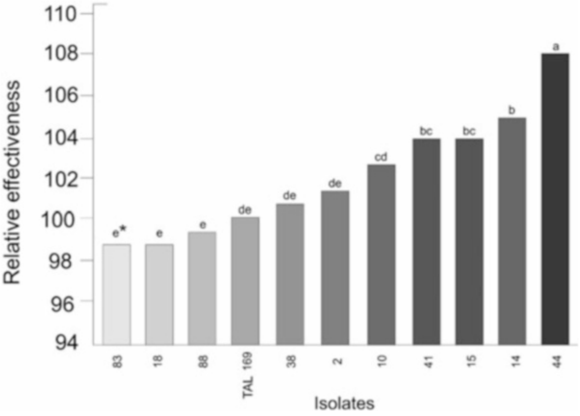


Fig. 7.9 Symbiotic Effectiveness of 10 Cowpea Bradyrhizobia Isolates Relative to an Adopted Standard Strain TAL 169. *: Bars with same letters are not significantly different at 5% level of significance (Source: Fening et al. 2002)

The potential for increasing the yield of cowpea and other legumes as well as improving the soil nitrogen status by using very effective indigenous isolates as inoculants therefore exist. At present there is lack of adequate information on the diversity, symbiotic characteristics, as well as the competitiveness for nodule occupancy of this native population of rhizobia.

Groundnut, an important legume in Ghana in terms of both production and consumption (Ofori 1993), is estimated to receive about 79% of its total nitrogen requirements from symbiotic association with rhizobia (Dakora et al. 1987).

The importance of soybean as a grain legume is gradually growing and gaining popularity in terms of cultivation and consumption in Ghana. Studies have shown that the majority of soybean cultivars cultivated are not readily nodulated by the indigenous rhizobia in most soils where trials have been carried out in Ghana (Abaidoo et al. 2000).

7.6 Conclusions and Recommendations

Recent trends in the agricultural sector indicate that for the first time the growth rate of the sector contracted by 2.9%. Part of the explanation for such a decline in agricultural growth is the decline soil fertility. So long as agriculture in Ghana remains a soil-based industry, there is no way that required yield increases of the major crops can be attained without ensuring that plants have an adequate and balanced supply of nutrients. Future strategies will have to redress this problem of declining soil fertility in order to create synergies with other yield increasing technologies.

The current decline in soil fertility may well lead to irreversible degradation and soil infertility unless steps are taken to improve soil management. The application of targeted, sufficient, and balanced quantities of inorganic fertilizers will be necessary to make nutrients available for high yields. Governments should take the necessary steps to facilitate the widespread and responsible use of chemical fertilizers. At the same time, every effort should be made to improve the availability and use of secondary nutrients and micronutrients, organic fertilizers, and soil-conservation practices.

Fertilizer use, access to credit and use of irrigation are closely linked – yet, in Ghana, farm-household access to these complementary services is low. Therefore, any successful intervention to promote fertilizer use in Ghana will have to be accompanied with complementary inputs and services – as a package.

Given the high variability of soils even at farm level, soil testing and mapping are a prerequisite for informed fertilizer use. Adequate funds should be available for research on fertilizer use to accurately inform fertilizer formulations to meet specific soil needs.

The use of integrated soil fertility management practices, along with other improve crop management technologies, and a conducive policy environment, are key components for attaining increases in agricultural growth.

Research on biological nitrogen-fixation as a low-cost "organic" approach to increasing nitrogen availability and organic matter content in soils should also be promoted.

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Chapter 8
Response of Rice, Maize and Millet to Fertilizers in Mali

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Abstract Maize, rice and millet yield are very low in Mali due to low fertilizer use. The research results reported here are based on work carried out in the different agroecological zones (AEZs) in Mali for Africa, with a structure of treatments allowing the determination of the response functions for nitrogen (N), phosphorus (P) and potassium (K) on maize, rice and millet. A diagnostic treatment including Zn, Mg, and B was compared with the same NPK treatment to evaluate the effect of micronutrients. The results will be combined with research conducted under similar agro-ecological conditions to develop robust response functions for the different crops and ensure greater profit in fertilizer use decisions.

The fertilizer rates that were tested within the framework of the study showed different effects according to crops and AEZs. The combinations across the three agro-ecological zones showed that higher rates such as those blankets recommended would not be economically profitable. The same observation was made for conventional and hybrid maize. For maize, the best combinations across the three agro-ecological zones were: 90N 10P 0K, 90N 30P 0K, 30N 40P 0K, 120N 30P 0k, 60N 30P 10K, 60N 30P 30K.

Application of N, P, and K did not affect yields of upland rice, but there were significant differences in the yields of lowland rice and irrigated rice. Average yields were 2.482, 2.808 and 4.71 t/ha for upland, lowland and irrigated rice respectively. A diagnostic treatment including N, P, K, Mg, S, Zn, and B had a significant effect on lowland rice (rain fed and irrigated) but not on upland rice compared to N, P, and K alone. Nutrients effects were specific to each area and production conditions. The Fertilizer Optimization Tool (FOT) developed in the framework of the OFRA project allowed to propose economic rates lower than the current recommendations and for each type of rice cropping system depending on the agro-ecological zones.

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The fertilizer rates that were tested showed significant differences between treatments, regardless of soil type. As sole crop, millet gave yields significantly higher than that usually found in farmers' fields around the station (1500 average against 800 to 1000 kg/ha). It is concluded that the application of 22.5 P combined with 40 or 60N and that of 30P without N and K significantly improve millet grain yield. The best yields were achieved with P rates higher than that recommended (46P2O5) for millet fertilization.

Keywords Maize • Rice • Millet • Fertilizer recommendation • Response function • Agro-ecological zone

Contents

8.1 Introduction

Maize, Rice and Millet are the main staple crops produced in Mali (Keita et al. 1991). Rice occupies more than 500,000 hectares. According to FAO (2013), rice consumption accounts for 25% of total cereal consumption, compared to less than 10% in 1961. This is due to increased urbanization and declining production of other crops as a result of irregular rainfall (Johnston and Bruulsema 2014). This rise in rice consumption has triggered increased production. In the same way, maize has emerged as one of the strategic cereals to ensure food security. Annual production increased from 50,000 tons (37,000 hectares) in 1980–1,500,000 tons (700,000 hectares) in 2010 (DNA report 2012). Maize has the highest yield of all dry cereals (FAOSTAT 2015) and has become the second major crop in terms of production. It accounts for 17% of cultivated lands in Mali and represents between 11% and 25% of the country's total cereal production with a peak of 25.68% of the cereals produced during the 2012/2013 crop year.

The increase in consumption don't meet the increased of production mainly due to the use of inputs such as fertilizers by smallholder farmers, hostile environmental conditions due to climate change, low levels of technology dissemination, crop pests and diseases (Bucheyeki et al. 2011; Rugumamu 2014). The standard fertilizer recommendations, developed long ago, have not delivered the expected results due to the low efficiency of fertilizer applications, which do not exceed 20% (Wopereis et al. 1999). Millet is widely cultivated in Mali, but since the 70s, a binary option combining phosphorus and nitrogen (without potassium) fertilizers was recommended for all soil types and across all agro-ecological zones of the country. Rates of 100 kg/ha of diammonium phosphate (18-46-0) at soil preparation and 50 kg/ha of urea (23-0-0) at stem elongation were recommended, hence the 41N20P0K formula. This recommendation over 30 years old is no longer appropriate and should be reviewed with a view to optimizing fertilizer use, and to propose more specific and cost-effective recommendations. In addition, these recommendations do not take into account farmers' financial capacities. This has led to the stagnation of fertilizer productivity.

The works reported here are part of a new research dynamic aiming at formulating recommendations that are specific to agro-ecological zones for small-scale farmers. The results will be combined with research conducted under similar agro-ecological conditions to develop robust response functions and regional recommendations for different rice ecologies

The objective of this study was to determine rice, Maize and millet response to fertilizers across different agro-ecological zones.

8.2 Materials and Methods

8.2.1 Study Sites

Figure 8.1 shows the major AEZs in Mali. The study was conducted in three agro-ecological zones in Mali (Sahel, North Sudan Savana and South Sudan Savana) for Maize and millet.

For rice, it was focused on irrigated rice in Niono, in the Inner Delta of the Niger River in the Sahel zone (400-600 mm), and rain fed rice in the upland and lowland areas of the pre-Guinean Savana, also called South Sudan Savana (1200–1400) respectively at Finkolo and Longorola.

The soils are classified as alfisoils. These soils are known as poor in organic matter (less than 2%) and phosphorus (Keita et al. 1991).

8.2.2 Plant Material

A conventional maize variety (**Sotubaka**) of 110–120 days, a maize hybrid (**Tièba**) of 110–115 days were used. For Rain fed Rice, a NERICA 4 was used for rain fed was used, and Kogoni91-1 (135 days) was use for irrigated rice. A millet variety (Toroniou C1) which is a local variety from Mali was used.

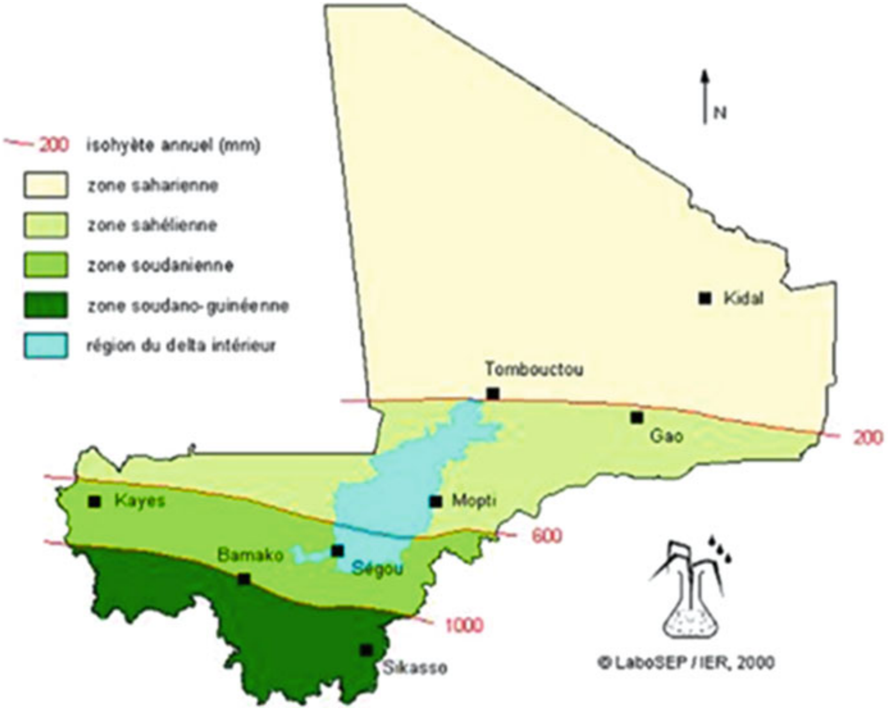

Fig. 8.1 The Agro-Ecological Zones of Mali (Sotuba Soil Lab 2000)

8.2.3 *Experimental Design*

On-station trials was implemented in randomized complete blocks design (RCBD) design. For Maize, each treatment was subdivided into 2 sub-plots of the Sotubaka variety and the Tiéba hybrid (Table 8.1).

In Maize, pearl millet and upland rice production, within row and for irrigated and lowland productions the rice was transplanted at four leaves stage.

P, K, and micronutrients were applied at emergence or after transplanting. Urea was applied as top dressing in two fractions: at emergence and at panicle initiation.

8.2.4 *Data Analysis*

An analysis of variance (ANOVA) was performed taking into account the nutrient levels. A non-linear asymptotic function has been determined for the nutrients for which crops response was registered. This equation is the following:

Table 8.1 Treatments used for maize, pearl millet, irrigated rice and rain fed rice

Maize			Pearl millet			Irrigated rice			Lowland rice			Upland rice		
N-rate	P-rate	K-rate	N-rate	P-rate	K-rate	N-rate	P-rate	K-rate	N-rate	P-rate	K-rate	N-rate	P-rate	K-rate
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	10	0	0	7,5	0	40	0	0	30	0	0	25	0	0
0	20	0	0	15	0	80	0	0	60	15	0	50	0	0
0	30	0	0	22,5	0	120	0	0	90	0	0	75	0	0
0	40	0	0	30	0	160	0	0	120	0	0	100	0	0
90	0	0	60	0	0	0	15	0	0	15	0	0	15	0
90	10	0	60	7,5	0	40	15	0	30	15	0	25	15	0
90	20	0	60	15	0	80	15	0	60	15	0	50	15	0
90	30	0	60	22,5	0	120	15	0	90	15	0	75	15	0
30	40	0	60	30	0	160	15	0	120	15	0	100	15	0
30	30	0	20	22,5	0	120	7.5	0	90	7.5	0	75	7.5	0
60	30	0	40	22,5	0	120	22.5	0	90	22.5	0	75	22.5	0
120	30	0	80	22,5	0	120	15	10	90	15	10	75	15	10
60	30	10	60	22,5	10	120	15	20	90	15	20	75	15	20
60	30	20	60	22,5	20	120	15	30	90	15	30	75	15	30
60	30	30	60	22,5	30	120	15	20[a]	90	15	20[a]	75	15	20[a]
90	30	20[a]	60	22,5	20[a]	120	15	20[a]						
200	80	0												

[a] ***diagnostic***

Diagnostic treatments was:
Maize: 90-30-20 + 15S-2,5Zn-10 Mg-5B
Pearl millet: 60-22,5-20 + 15S-2.5Zn-10 Mg-0.5B
Irrigated rice: 120-15-20 + 15S-2.5Zn-10 Mg-0.5B
Lowland Rice: 90-15-20 + 15S-2.5Zn-10 Mg-0.5B
Upland rice: 75-15-20 + 15S-2.5Zn-10 Mg-0.5B

$$Y = a - bc^{n}$$

(Where *a* is the maximum yield obtained from the application of a given nutrient, *b* is the yield gain related to the application of the nutrient, *c^n* determines the shape of the curvilinear response, *c* is the coefficient of curvature and N is the applied nutrient rate).

The response to N for each P level, the response to P for each K level and the response to K for each NP level were determined.

The effect of micronutrients was determined for each crops and AEZs.

8.3 Results

8.3.1 Crops Response to Fertiliser

Table 8.2 below shows the results of the ANOVA for maize

A significant difference was observed in the yield of the varieties ($P = 0.002$ and 0.004) in Bougouni and Samanko, but there is any difference in Kolombada and any treatment/variety interaction. The high rate NP rate (200-80) and the diagnosis treatment gave the best yields with respectively 6377 kg/ha and 5823 kg/ha but were not significantly different from the others.

8.3.2 Rice Response to Fertiliser

For irrigated rice, the results of the ANOVA (Table 8.3) showed for the vertisoil, a difference in paddy yield at the 1% threshold with a very high coefficient of variation (CV) of 33%, probably related to the diagnostic treatments. There was no difference in the second soil clay loamy soil.

In rain fed rice production, the ANOVA (Table 8.4) did not show significant differences between treatments on upland rice as opposed to lowland rice where the treatments had a significant effect at the threshold of 1% on the paddy with an average of 2.8 $T.ha^{-1}$ and a coefficient of variation (CV) of 12.5%.

For Pearl millet, the ANOVA (Table 8.5) showed significant differences between treatments, regardless of soil type. Diagnostic treatment had any impact on millet yield. On the other hand, no difference was observed with the effect of phosphorus alone or associated with nitrogen.

On Oxic Haplustalf, five treatments scored at the top of the rankings: T13 (80N-22.5P-0K), T16 (60N-22.5P-30K), T9 (60N-22.5P-0K), T12 -22.5P-OK) and T5 (ON-30P-0 K). The millet yields observed under these treatments (1610 kg ha $^{-1}$, 1575 kg ha $^{-1}$, 1570 kg ha $^{-1}$, 1540 kg ha $^{-1}$ and 1535 kg ha $^{-1}$, respectively) were equivalent to each other.

Table 8.2 ANOVA table for Maize in Mandingue Plateau

Nut rates (kg/ha)			SSS_Bou	NSS_Kol	NSS_Sam	SSS_Bou	NSS_Kol	NSS_Sam
N	P	K	Sotubaka variety			Sotubaka variety		
0	0	0	2.869	1.880	2.558	2.708	2.339	2.962
0	10	0	2.345	2.435	3.804	3.229	2.839	3.638
0	20	0	3.501	1.498	2.901	3.177	2.926	3.850
0	30	0	2.530	3.637	3.576	3.125	3.520	4.154
0	40	0	2.912	1.712	4.258	2.917	2.228	3.770
90	0	0	4.168	3.712	4.522	4.740	2.573	4.052
90	10	0	5.420	2.950	3.997	4.688	2.985	4.387
90	20	0	4.467	2.020	4.788	5.833	2.210	3.786
90	30	0	4.661	2.973	3.544	5.260	3.108	4.220
30	40	0	5.260	2.663	3.705	4.115	2.969	3.097
30	30	0	3.865	2.096	4.582	4.688	2.496	5.022
60	30	0	4.376	2.223	3.758	6.510	2.146	4.716
120	30	0	5.561	2.411	4.461	5.781	2.803	4.864
60	30	10	4.162	3.289	4.486	5.156	2.923	4.008
60	30	20	4.522	2.855	4.147	5.365	2.375	3.220
60	30	30	4.260	3.889	4.081	4.844	3.317	4.659
90	30	0*	4.918	2.279	5.052	5.677	2.459	4.001
200	80	0	6.407	2.478	5.562	5.469	3.326	5.251
		T P	0.002	0.338	0.004			
		T*V P	0.469	0.133	0.297			
		Mean	4.205	2.682	4.096			
		CV sotubaka	32.3	42.0	21.0			
		CV tieba	25.3	21.0	18.3			
		Diagnos P	0.357		0.099			
		High NP P	0.051		0.001			

On mineral hydromorphic soil (Aquic haplustalf), treatment 60–30–0 leads the ranking with an average millet grain yield of 1475 kg ha^{-1}.

Large plot size and spatial variability affected the normal expression of the effect of treatments and their interpretations.

On the other hand, crops were more affected by rainfall conditions on hydromorphic mineral soils (water stagnation during full vegetative period and water deficit at flowering and fruit setting). The abundance of rains from the second 10 days of August to the first 10 days of September resulted in water stagnation in depressed areas, thus affecting crop growth and development. Also, on this soil, the water deficit recorded in October affected crop flowering and fruit setting.

Table 8.3 ANOVA table for Irrigated rice in Niono (Sahel zone)

N	P	K	NioMour	NioDan
0	0	0	3.3642	8.1197
40	0	0	5.2823	7.927
80	0	0	4.3122	8.1964
120	0	0	3.8121	7.611
160	0	0	4.5619	7.8749
0	15	0	4.3499	7.3642
40	15	0	3.241	7.8177
80	15	0	4.0067	9.118
120	15	0	4.2786	7.3307
160	15	0	4.5417	8.4326
120	7.5	0	3.5673	7.5471
120	22.5	0	4.1525	8.2974
120	15	10	3.5158	8.1428
120	15	20	5.297	7.3435
120	15	30	4.4345	7.8439
120	15	20*	8.5621	8.5714
120	15	USG	8.7771	7.2857
Trt P			0.0028	0.654
Mean			4.71	7.93
CV			33.16	12.16
Diag P			0.129	0.0154
USG P			0.9405	0.0102

8.3.3 Crops Responses to Nutrient NPK

Figures 8.2a–e show crops responses to NPK alone or in combination through the three AEZs.

Significant response to N when applied alone occurred only for rice. The maximum yield increase reached around 60N for irrigated rice. When applied with a constant amount of P (15 for Rice, 30 for Maize and 22.5 for Pearl Millet) led to a slight increase of grain yield. The Yield continue increasing for maize but he maximum profitable seems to be limited at 60N. With 15P, irrigated rice reaches its maximum value around 5T/ha whatever the nitrogen level. For lowland rice, maximum yield is reached with 60N.

The best maize responses in all localities were obtained with combinations of P and N (PwN) nutrients in a ratio of 30 or 40 kg/ha of P when 90 kg/ha of N were applied

Potassium had a very limited effect on the yield.

Table 8.4 ANOVA table for Irrigated rice in Niono (Sahel zone)

Grain LL Rice				Grain UL Rice			
Trt P	0.021			Trt P	0.836		
Mean	2.808			Mean	2.482		
CV	12.490			CV	27.94		
Diag P	NS			Diag P	NS		
N	P	K		N	P	K	Gr yield
0	0	0	2.515	0	0	0	2.736
30	0	0	2.170	25	0	0	2.524
60	15	0	2.909	50	0	0	2.432
90	0	0	3.057	75	0	0	2.489
120	0	0	3.008	100	0	0	2.176
0	15	0	2.318	0	15	0	2.283
30	15	0	2.712	25	15	0	2.742
60	15	0	3.353	50	15	0	2.414
90	15	0	2.762	75	15	0	2.123
120	15	0	3.057	100	15	0	2.552
90	7.5	0	2.909	75	7.5	0	2.109
90	22.5	0	3.008	75	22.5	0	2.445
90	15	10	3.008	75	15	10	2.696
90	15	20	2.416	75	15	20	3.110
90	15	30	2.860	75	15	30	1.941
90	15	20*	2.860	75	15	20*	2.937

8.3.3.1 Effect of Diagnostic Treatment

Figure 8.3 shows the effect of an application of 15S, 10 Mg, 2.5B, 0.5Zn compared to the treatment which received the same level of NPK. It can be observed that the application of these nutrients had no significant effect on maize and pearl millet. The maximum effect was observed on irrigated rice. This effect was very significant on irrigated rice (around 40% increase)And even the study could not show which nutrient is the more limiting, we can assume that it could be the Zinc according to the alkalinity issues in that zone (Dicko 2005)

The optimal recommendations proposed by FOT are lower than the current recommendations, especially for irrigated rice. For lowland rice and upland rice, the recommendations are similar.

This indicates that the use of fertilizers at the currently recommended rates would miss the opportunity to maximize profit by applying too much fertilizer. Thus, resource-poor farmers can improve the profitability of their fertilizers by opting for the segment of the response curve before the plateau.

However, it should be noted that this recommendation focuses more on ensuring economic returns than maximizing yields. It is important to take this into account in order to adjust fertilizer application according to the nutrients that may be lacking

Table 8.5 ANOVA table for millet

N	P	K	GrainAcquic	GrainOxic
0	0	0	1.3494	1.4385
0	7.5	0	1.4139	1.6605
0	15	0	1.5053	1.2701
0	22.5	0	1.4667	1.4898
0	30	0	1.3261	1.9
60	0	0	1.6193	1.4271
60	7.5	0	1.5023	1.6181
60	15	0	1.5535	1.6904
60	22.5	0	1.9891	1.7057
60	30	0	1.7127	1.5361
20	22.5	0	1.7218	1.9082
40	22.5	0	1.6149	1.7265
80	22.5	0	1.1777	1.7542
60	22.5	10	1.6403	1.5186
60	22.5	20	1.5664	1.4149
60	22.5	30	1.5048	1.5539
60	22.5	20*	1.6067	1.4423
		TrtP	0.0002	0.0045
		Mean	1393.1	1439
		CV	20.85	22.33
		Lsd0.05	335.4	371.1
		Diag P	0.0227	0.0522
		P	0.5972	0.3546
		PxN	0.5995	0.1242

* Diagnostic Treatment

for the crop. Therefore, it is important that any recommendations should be made within the framework of Integrated Soil Fertility Management. This is confirmed by (unpublished) works on irrigated rice and rain fed rice and shows that adding organic matter would allow to save the first urea application.

Tables 8.6, 8.7 and 8.8 present fertilizer recommendations. The optimal recommendations based on crops response to nutrients appear to be lower than current recommendations for nitrogen, but higher than currently recommended phosphorus rates.

It should be noted, however, that this recommendation focuses more on Optimizing Economic returns (Fig. 8.4) than maximizing yields. EOR determined on the basis of 50 kg fertilizer: urea at 16,000; TSP at 13,000; DAP at 20,000; and KCl at 15,000; 1 kg of rice at 130 CFA/kg.

It is important to take this into account in order to adjust fertilizer applications according to the nutrients that may be lacking for the crop. For this reason any recommendations should be made within the framework of the Integrated Soil Fertility Management to adapt recommendations to cropping systems that follow changes in rainfall amounts and distribution from south to north. This means that

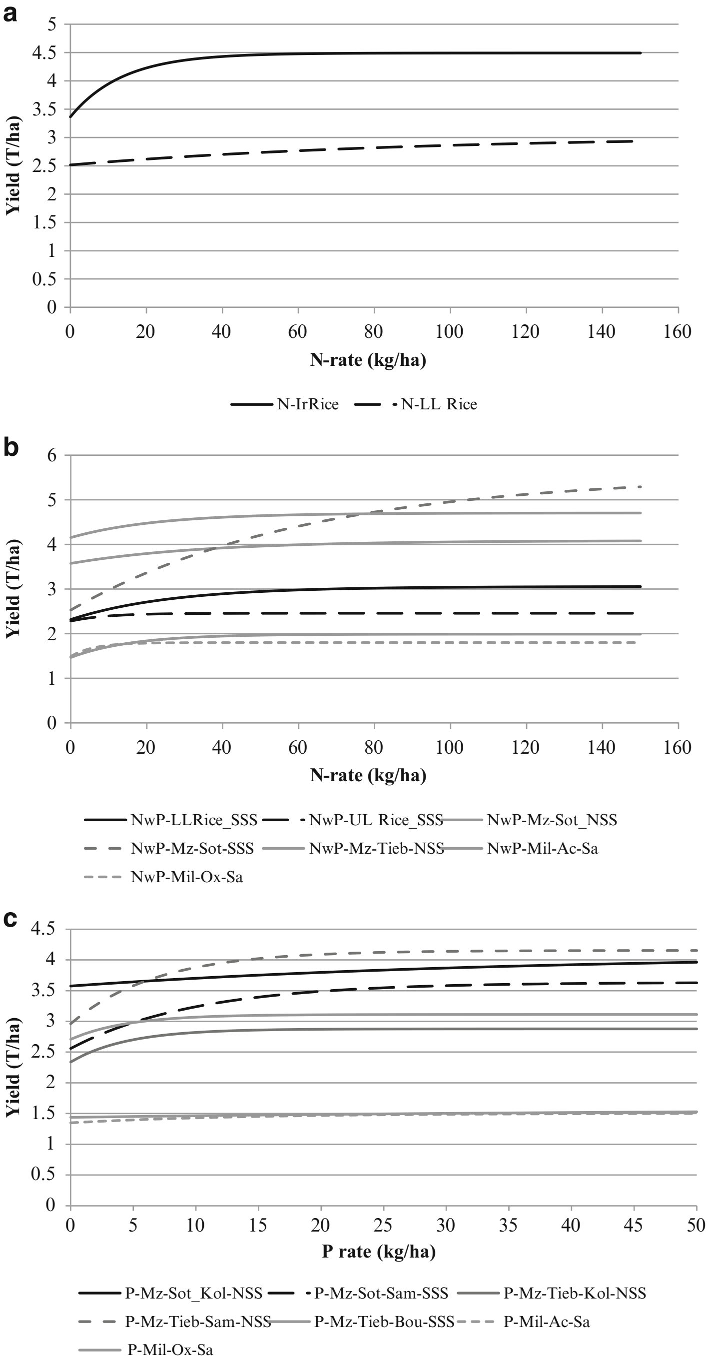

Fig. 8.2 crops response to NPK. (**a**) Irrigated (Ir Rice) and Lowland (LL rice) response to N applied alone (Y 1⁄4); (**b**) Lowland rice (LLrice), Upland Rice (ULrice), Maize (Mz) and Pearl milet (Mil) responses to N when P is applied; (**c**) Maize (Mz) and Pearl Millet (Mil) response to P applied alone; (**d**) Irrigated rice (Ir rice), Maize (Mz) and Pearl Millet (Mil) response to P when N applied; (**e**) Irrigated rice (Ir rice), Maize (Mz) and Peral Millet response to K when N&P applied

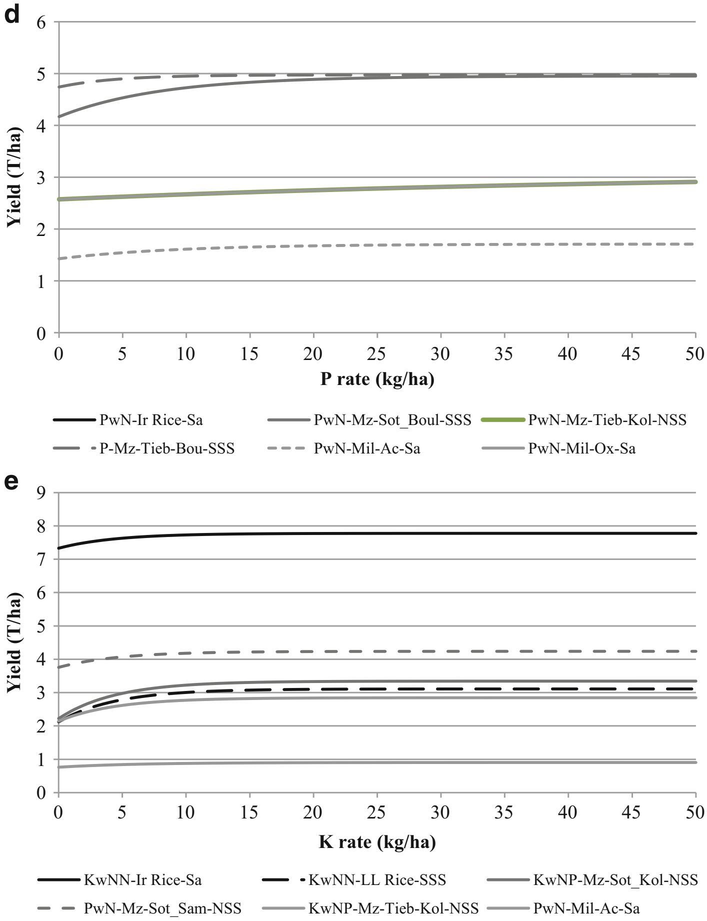

Fig. 8.2 (continued)

good nutrient management is essential to achieve best yields of crops from fertilizer use describe by Johnston and Bruulsema (2014) as the principle of 4R, Right source of nutrients provide at the Right rate, at the Right time for efficient uptake by the crop, and in the Right place to be accessible to plant roots.

8.4 Conclusion

The study showed that the best maize responses in all localities were obtained with combinations of P and N (PwN) nutrients at the rate of 30 or 40 kg/ha of P when 90 kg/ha of N were applied and N and P (NwP) in the rate of 60 or 120 kg/ha of N

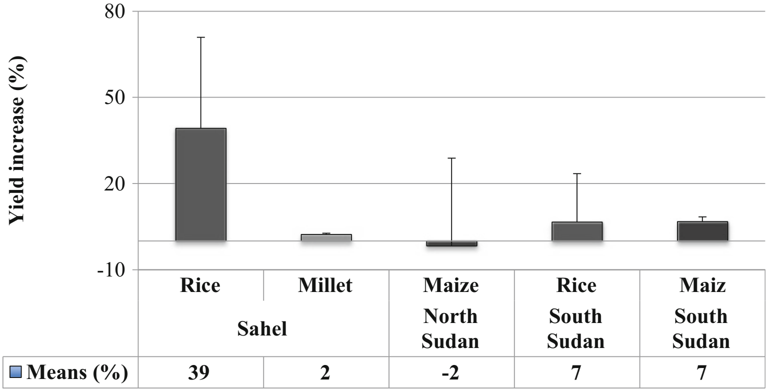

Fig. 8.3 Effect of micronutrients on rice (irrigated in the Sahel, Rain fed Lowland in the South Sudan Savana), Maize and Pearl Millet in the AEZs

when 30 kg/ha of P were applied. Potassium had no effect on the yield and biomass of Sotubaka and Tieba on the Mandingue Plateau and the Upper Bani-Niger, and had a relatively low effect on the Koutiala Plateau.

It is important to introduce micronutrients and organic matter into the fertilization taking into account the integrated soil fertility management approach.

Rice is a crop that responds well to the use of fertilizers, but any recommendations that are meant to be efficient should be adapted to the cropping systems and the agro-ecological zones. This refers to good fertilizer management practices called 4Rs by Johnston and Bruulsema (2014. This was confirmed in this study by the use of a diagnostic treatment including micronutrients. The micronutrient application generated a significant yield increase for rice in irrigated and lowland conditions, even more so when Urea Super Granule was used. These results should be refined, especially to discriminate the most crucial micronutrient according to the rice ecologies.

The results show the importance of the application of 22.5 P plus 40 or 60N and 30P without N and without K for the improvement of millet grain yield. The best yields were obtained with P rates higher than those recommended (46P2O5) for millet fertilization. However, for reasons of economic profitability, these recommendations could be adjusted by decreasing nitrogen rates and by slightly increasing phosphorus rates. It also appears that in case of risk of waterlogging, the application of nutrients other than NPK proves necessary.

Table 8.6 Optimized recommendation for Sahel (200–600 mm)

	Response coefficients, Yield = a – bc^r				Effect of nutrient rate (kg/ha) on grain yield (t/ha)				Recommended nutrient rate	
	r = elemental nutrient rate									
		A	B	C	0–30	30–60	60–90	90–120	EOR†	Rec
Crop	Nutrient	t/ha			t/ha				Kg/ha	
Rice (irrigated)	N	4.492125	1.127925	0.93	0.470	0.078	0.013	0.002	48	120
					0–5	**5–10**	**10–15**	**15–20**		
Pearl millet	P	1.717	0.768	0.940	0.204	0.150	0.110	0.081	23	10
Maize	P	1.275	0.687	0.951	0.153	0.119	0.092	0.072	0	7
Rice (Irrigated)	P	5.19	0.189	0.919	0.065	0.043	0.028	0.018	14	20
Rice (irrigated	K	6.036	0.223	0.750	0.170	0.040	0.010	0.002	12	50

† EOR (in CFA) determined from grain and fertilizers values, considering an average value of others charges

Table 8.7 Optimized recommendation for North Sudan Savannah (600–1000 mm)

	Response coefficients, Yield = a – bc^r									
	r = elemental nutrient rate				Effect of nutrient rate (kg/ha) on grain yield (t/ha)				Recommended nutrient rate	
		A	B	C	0–30	30–60	60–90	90–120	EOR†	Rec
Crop	Nutrient	t/ha			t/ha				Kg/ha	
Rice, lowland	N	2.483	0.429	0.974	0.234	0.106	0.048	0.022	67	60–80
Maize	N	2.290	1.619	0.960	1.143	0.336	0.099	0.029	54	84
					0–5	**5–10**	**10–15**	**15–20**		
Maize	P	2.868	0.295	0.928	0.092	0.063	0.044	0.030	3	7

† EOR (in CFA) determined from grain and fertilizers values, considering an average value of others charges

Table 8.8 Optimized recommendation for South Sudan Savannah (1000–12,000 mm)

	Response coefficients, Yield = a – bc^r									
	r = elemental nutrient rate				Effect of nutrient rate (kg/ha) on grain yield (t/ha)				Recommended nutrient rate	
		A	B	C	0–30	30–60	60–90	90–120	EOR†	Rec
Crop	Nutrient	t/ha			t/ha				Kg/ha	
Maize	N	3.000	1.760	0.970	1.054	0.423	0.170	0.068	65	84
Rice, upland	N	4.655	1.908	0.988	0.580	0.404	0.281	0.196	70	60–80
Rice, lowland	N	2.482	0.428	0.970	0.256	0.103	0.041	0.017	62	60–80
					0–5	**5–10**	**10–15**	**15–20**		
Maize	P	2.868	0.295	0.928	0.092	0.063	0.044	0.030	2	7
Rice, upland	P	3.633	0.979	0.904	0.388	0.234	0.141	0.085	13	20
Pearl millet	P	1.520	0.129	0.900	0.053	0.031	0.018	0.011	2	10
Rice, upland	K	4.439	0.838	0.800	0.563	0.185	0.060	0.020	25	
Rice, lowland	K	1.950	0.091	0.961	0.016	0.013	0.011	0.009	14	

† EOR (in CFA) determined from grain and fertilizers values, considering an average value of others charges

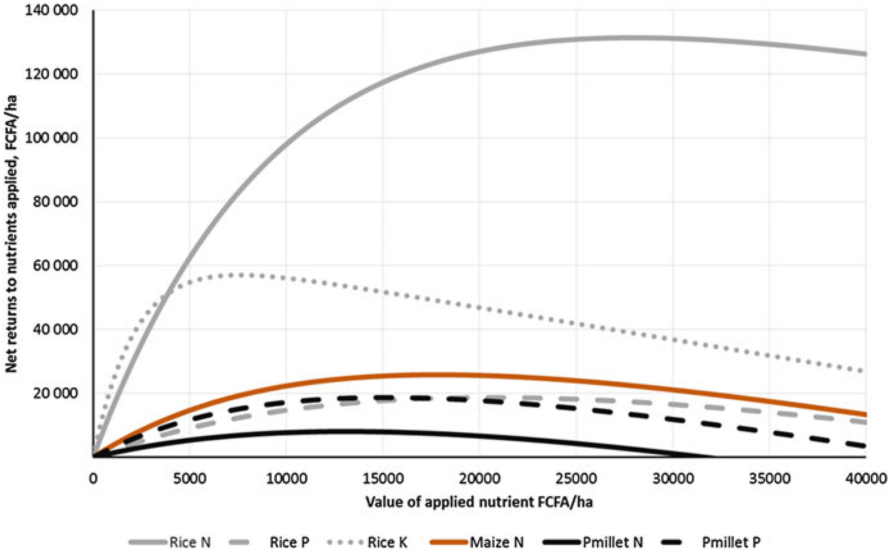

Fig. 8.4 Net returns from investments in fertilizers for the study crops

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Chapter 9

Role of Local Agro-minerals in Mineral Fertilizer Recommandations for Crops: Examples of Some West Africa Phosphate Rocks

François Lompo, Andre Bationo, Michel P. Sedogo, Vincent B. Bado, Victor Hien, and Badiori Ouattara

Abstract One of the major constraints to enhanced crop productivity in West Africa is low soil fertility and particularly soil deficiency in available phosphorus (P). When P is limiting, crop production is greatly compromised even though the other nutrients are available in large amounts. The use of soluble P fertilizers is hampered by the cost of the P fertilizers commercially available, too high for resource-poor farmers. Therefore, exploitation of the locally available phosphate rock (PR) deposits represents an alternative for soil P supply to ensure mineral plant nutrition. The effectiveness of a particular PR depends mainly on its chemical and mineralogical composition, and to some extent on environmental conditions, crop type and management practices. This communication highlights some results of the research works that have been carried out in the region to enhance the direct use of PR in agriculture and how theses PR can be integrated in fertilizer recommendations for crops. Direct application of phosphate rocks may be an economical alternative to the use of the more expensive imported water-soluble P fertilizers for certain crops and soils.

Keywords Agro minerals • Crops • Rock phosphate • West Africa

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Contents

9.1 Introduction

In the Sahelian zones of West Africa, agriculture is practiced under biophysical and socio-economic conditions characterized among others by: (i) erratic rainfall, with very marked spatio-temporal variation, (ii) Soils with a predominantly sandy texture, phosphorus-deficient, prone to runoff and erosion, poor in organic matter, and whose already low inherent fertility is exacerbated by mining agriculture practices, (iii) farmers' low investment capacities, and (iv) lack of incentive-based agricultural policies. In addition, there is pressure on crops by insects, diseases and weeds. Under these conditions, it is not surprising that ensuring food and nutrition security is at the center of Governments' concerns. According to FAO (2004), of the 840 million people who do not meet their energy needs, 790 million live in the developing countries of which 200 million Africans living in a situation of more or less chronic famine. According to AGRA (2014), about 223 million Africans south of the Sahara are chronically under-nourished and this number could be increased by 132 million in 2050 with the impacts of climate change. Food production in Africa has declined over the last two decades despite the global upward trend at the global level. While in Asia and Latin America over the past 35 years per capita cereal production has increased from 200 to 250 kg/person, it decreased in Africa from 150 to 130 kg/person.

In West Africa, only the following five countries have reached the threshold of 2400 kcal/pers. set by FAO: Benin, Côte dIvoire, Ghana, Mauritania and Nigeria (Ag 2004). According to Shrimpton (2002), the proportion of the population living on less than $1/day ranges from 12.3% in Côte d'Ivoire to 60% in Burkina Faso, Mali and Niger.

This explains why Africa received food aid in 2000 estimated at 2.8 million tons, a quarter of the world total. According to WRI (2014), Africa South of the Sahara will have to produce 360% more than it produced in 2006 to feed its population in 2050.

Therefore, one of the major challenges for African agriculture, in particular, in Africa south of the Sahara, and especially West Africa, is "to produce more and better to feed a growing population, while developing an important natural potential not only by using the widest possible scope for progress but also by taking advantage of the rise in agricultural prices."(AFD 2008). Another challenge is to promote a human capital available, through substantial support to family farmers, who in Africa south of the Sahara account for more than 80% of producers and who directly employ about 170 million people.

Despite this rather somber picture of the situation in Africa south of the Sahara, there are more and more success stories on strategies for the development and adoption of integrated soil fertility management technologies. The benefits of improving soil fertility at farm level as well as at national and global levels are increasingly well perceived by the international community.

However, the recommendations of fertilizer formulas must be well adapted to crops, according to the climatic and pedological characteristics of their production areas. These fertilizer formulas must be also economically profitable and enable sustainable production. Local agro-minerals, especially phosphate rocks, because of their availability and quality as soil amendment, allow to reduce crop production costs and contribute to the sustainable improvement of soil fertility.

9.2 Potential for Improving Agricultural Production and Productivity in West Africa

Compared to other continents, the performance of African agriculture is low (Fig. 9.1). While cereal yields have evolved positively from slightly over 2 t ha^{-1} en 1960 to over 6,5 t ha^{-1} en 2010 in the USA and Europe, those observed in

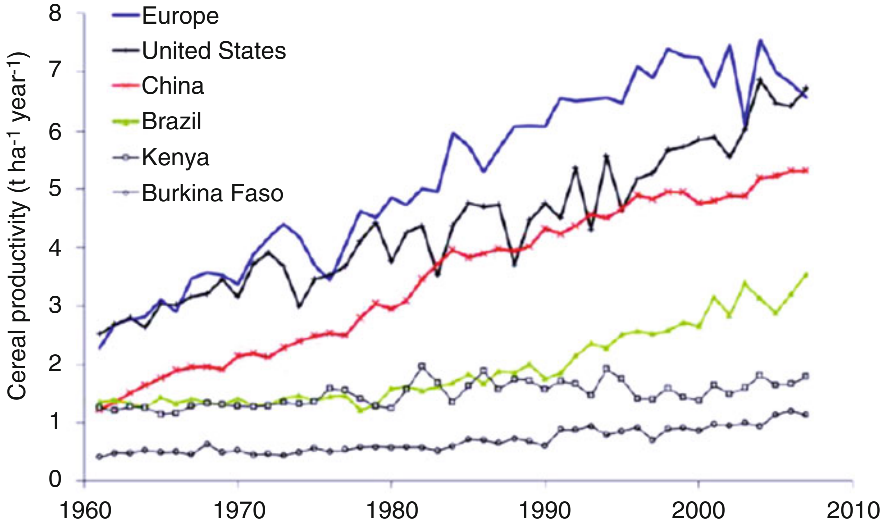

Fig. 9.1 Comparative cereal yields in different continents (Pera 2016)

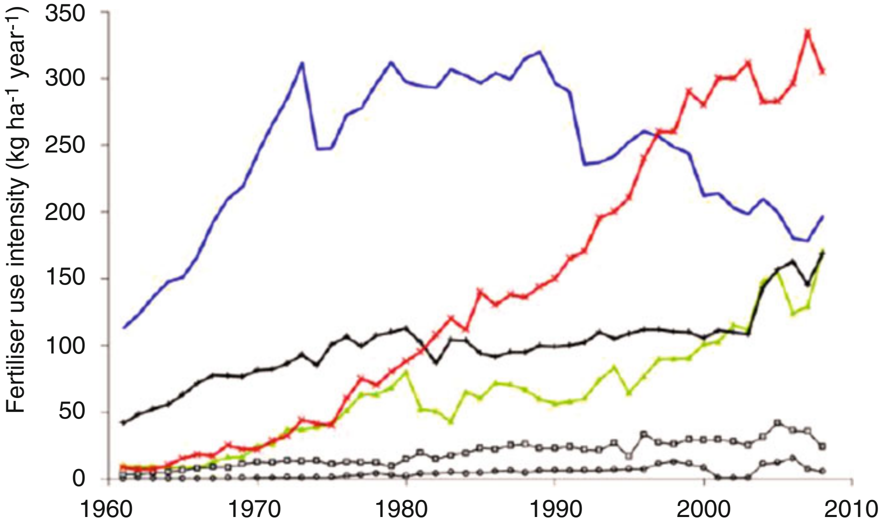

Fig. 9.2 Intensity of fertilizer use in different continents (Source: Pera 2016)

sub-Saharan Africa have increased from an average of 500 kg ha^{-1} to about 1 t ha^{-1} on average over the same period.

Referring to the amounts of fertilizers used in the same situations (Fig. 9.2), while in countries such as the United States, China and Brazil, the intensity of fertilizer use is on average above 100 kg ha^{-1}an^{-1}, this intensity is around 10 kg ha $^{-1}$an^{-1}en Afrique. In this context of mining agriculture, the mineral balances are increasingly negative, as shown in Fig. 9.3. Annual losses of 23 kg-N ha^{-1}, 6 kg-P_2O_5ha^{-1}, and 16 kg-K_2O ha^{-1}, are recorded in sub-Saharan Africa, mainly due to nutrient exports by productions (straw and grain), erosion and runoff (Henao and Baanante 2006), without any consequent compensation through the use of mineral fertilizers and/or organic amendments. Thus, nitrogen losses per year reach nearly 4.4 million tons compared to intakes estimated at only 0.8 million tons/year.

Considering intensification as an improvement in production per hectare due to an increase in labor, capital or new knowledge/techniques (Tiffen et al. 1994) and in view of the data in Fig. 9.4 showing the current and potential yields of major cereal crops in West Africa, it can be reasonably expected that farmers in this area will improve their living conditions through agricultural activities. Various traditional and improved technologies exist and can be used for this purpose.

Integrated soil fertility management plays an important role in the sustainable improvement of agricultural productivity in sub-Saharan Africa. In Sahelian agricultural production systems dominated by family-type farms, strong pressure on natural resources, especially on soils, has virtually eliminated the practice of fallow previously used to restore soil fertility.

Other factors such as low inherent soil fertility, soil depletion, low rates of return on investments in soil fertility, and low investment capacity of many smallholder

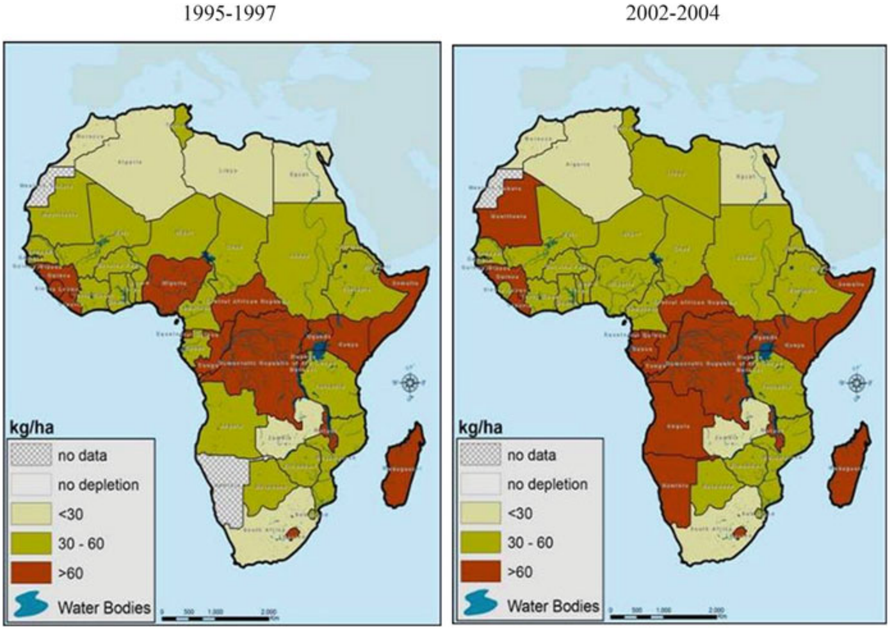

Fig. 9.3 Mineral balances on the African continent (Source: Henao and Baanante 2006)

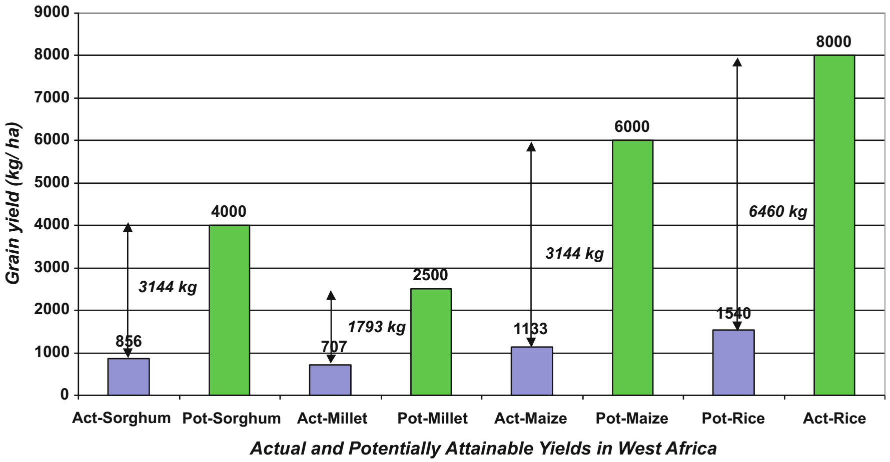

Fig. 9.4 Actual and potential yields of different cereals in West Africa

farmers are contributing to low soil fertility and low productivity in sub-Saharan Africa.

Paradoxically, sub-Sahan Africa has considerable potential for increasing agricultural productivity and production, and thus increase the contribution of agriculture to national wealth.

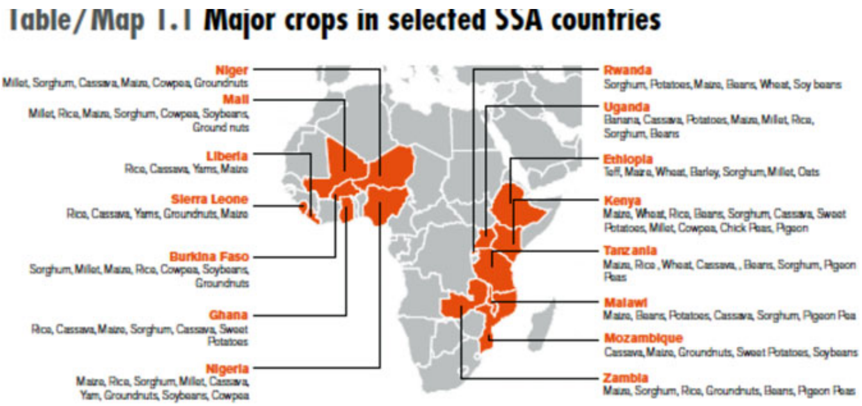

Fig. 9.5 Major crops in Africa south of Sahara (Source: AGRA 2014)

Of the 15 production systems identified in sub-Saharan Africa (Dixon et al. 2001), the most common in West Africa are:

- The agro-pastoral system millet/sorghum: This system is found in the semi-arid agro-ecological zone of West Africa. This area is characterized by an average annual rainfall of between 350 and 800 mm; strong pressure on arable land; high vulnerability of the system due to drought and climate change. Livestock farming is as important as agriculture. Millet and sorghum are the main staples and are intended for self-consumption; they are often cultivated in rotation or in association with cash crops such as cowpea, groundnut and sesame. Short to intermediate cycle maize is increasingly present. Rainfed rice is also increasingly present; it is grown in improved or unimproved wetlands and in the irrigated areas downstream of the water retention systems in increasing numbers.
- The mixed system of cereals-roots or tubers is more common in the sub-humid and humid agroecological zones of West Africa. The average annual rainfall varies between 800 mm and over 1100 mm. There is a wide variety of crops including maize, sorghum, millet, cowpea, groundnut, tuber crops, cotton, rice, fruit and vegetable crops.
- The pastoral system is practiced in the arid agroecological zone with an average annual rainfall of less than 350 mm. The potential for agriculture is very limited; this is the transhumance area.

This rich agro-ecological diversity favors the practice of a wide variety of crops (Fig. 9.5), with different requirements in terms of soil types and cropping practices, including those related to fertilization. These different crops are grown on five types of soils whose distribution in the countries of West Africa is indicated in Table 9.1. To these types of soils, must be added the Vertisols which represent around 1% of the soils in West Africa (Bationo 2008).

Table 9.1 Distribution (%) of the main types of soil in West African countries

Country	Arenosols (Psammients)	Lixisols (Alfisols)	Nitisols (Ultisols + Alfisols)	Acrisols (Ultisols)	Ferrasols (Oxisols)
Benin	–	**80**	**6**	–	–
Burkina Faso	**6**	**46**	–	–	–
Côte d'Ivoire	–	–	–	**72**	–
Gambia	–	–	**25**	–	–
Ghana	–	**52**	–	**25**	–
Guinea	–	–	–	**22**	**13**
Guinea Bissau	–	**55**	**5**	–	**18**
Mali	**15**	–	–	–	–
Mauritania	**10**	–	–	–	–
Niger	**30**	–	–	–	–
Nigeria	**13**	**34**	**14**	**5**	–
Liberia	–	–	–	**8**	**79**
Senegal	**30**	–	–	–	**70**
Sierra Leone	–	–	–	–	**70**
Togo	–	**59**	**11**	–	–

Source: Bationo (2008)

Lixisols (leached tropical ferruginous soils according to the French classification) are found in tropical and subtropical areas, and in high temperature regions with a marked dry season. They are characterized by high levels of low active clays with low nutrient retention capacity but with high cation saturation. The use of Lixisols for sustainable agricultural production requires the application of organic and mineral fertilizers.

Ferralsols (Ferralitic soils according to the French classification) are found mainly in the humid tropics. They are rich in kaolinite and sesquioxides, which are at the root of the high P-binding capacity in this type of soil. Their cation exchange capacity is low and they are most often deficient in molybdenum. Ferralsols have good physical properties (depth, permeability, drainage, ease of tillage, etc.). On the other hand, these soils are chemically poor (low cation retention capacity, low N, K, Ca, Mg and S contents). These are usually acidic soils. The fertility management of ferralsols very often requires the use of lime to fight against aluminum toxicity, but also to increase the CEC. The application of phosphate rocks also allows to correct P deficiency for a number of years.

Acrisols are found in humid tropics and subtropics and in high temperature regions. They are fairly or highly desaturated ferralitic soils in the French classification. They have a clayey B horizon and are usually acidic. They are typically nutrient deficient soils. They have high aluminum content, which gives them high phosphorus-binding capacity.

Table 9.2 Chemical characteristics of granitic soils in different agro-ecological zones of West Africa

Agroecological zone	Depth (cm)	pH H_2O	Org. C. (mg kg^{-1})	Total N (mg kg^{-1})	Total P (mg kg-1)	CEC (cmol kg^{-1})	Saturation level (%)
Equatorial	**0–20**	**5,3**	**24,5**	**160**	**628**	**88**	**21**
Forest	**20–50**	**5,1**	**15,4**	**1,03**	**644**	**66**	**16**
Guinean	**0–20**	**5,7**	**11,7**	**1,39**	**392**	**63**	**60**
Savanna	**20–50**	**5,5**	**6,8**	**0,79**	**390**	**56**	**42**
Soudanian	**0–20**	**6,8**	**3,3**	**0,49**	**287**	**93**	**93**
Savanna	**20–50**	**7,1**	**4,3**	**0,61**	**285**	**87**	**90**

Arenosols are sandy-textured soils including dune soils in desert areas. They are found in arid lands, in humid and sub-humid temperate zones. These are undeveloped mineral soils, and slightly developed soils in the French classification. These are soils with a light texture, high permeability and low water storage and nutrient retention capacity.

Nitisols (Fersial soils in the French classification) are deep, well-drained soils. The clay content of the surface horizon is greater than 30%. These are soils with a high level of inherent fertility. They may exhibit manganese toxicity and high phosphorus binding capacity. Nitisols are found mostly in the tropical zone, especially in uplands.

Vertisols are soils with high agricultural potential. These are soils with high clay content. Their physical properties constitute real constraints which limit their development especially the preparation of this type of soil and water management.

Table 9.2 presents the chemical characteristics of soils in the different agro-ecological zones of West Africa. It clearly shows that the soils of the equatorial, forest and Guinean zones are richer in organic matter, nitrogen and phosphorus than other areas.

Generally, the soils in tropical Africa are very old and come from the alteration of parental materials dating from the Precambrian. Their physicochemical properties are strongly related to these parental materials but also to climate characteristics. Lixisols, Ferralsols and Acrisols contain large amounts of iron and aluminum oxides which only partially cover the surface of the soil particles. In soils where iron and aluminum oxides form a thick and stable envelope around clay particles, there is a strong fixation or even occlusion of phosphorus. Phosphorus deficiency constitutes the major constraint to agricultural production in West Africa. In Africa south of the Sahara, 80% of the soils are P deficient (Bationo 2008).

This P deficiency has been evidenced by numerous authors among them Dabin (1974), Boyer (1981), Bationo (2008). P deficiency originates in the nature of the geological substratum and its evolution in the formation of tropical soils and in the low organic matter content and the depletion of the nutrients reserves of the soils under cultivation. Under tropical conditions characterized by high temperatures and alternating wetting and drying phenomena, the mineralization of soil organic matter (already low) is rapid, leading to soil depletion and subsequent retrogradation of phosphorus from fertilizers. Organic phosphorus, which accounts for 20–60% of total soil P, is related to the content and the level of development of soil organic matter.

Boyer (1982) reports that soils resulting from long pedogenesis (as is the case with most tropical soils) are characterized by a predominance of P-forms linked to aluminum (P-Al) and iron (P-Fe) which are not easily accessible to plants.

Paradoxically, in sub-Saharan Africa the use of phosphate fertilizers is the lowest (1.6 kg per ha per year) compared to 7.9 kg and 14.9 kg $\mathrm{ha}^{-1}\mathrm{an}^{-1}$ respectively in Latin America and in Asia.

The phosphate fertilizers used on crops (TSP, DAP, etc.) are imported, while Africa has large deposits of phosphate rocks which unfortunately are not sufficiently exploited.

9.3 Review of Agromineral Potential in Africa

Africa has significant agro-mineral deposits that can provide nutrients (N, P, K, Ca, Mg, S) for crops. Some of these deposits are present in West Africa (Mokwunye and Bationo 2006). Van Kauwenbergh (2006) and Van Straaten (2007) have made an inventory of these agro-mineral resources and their use.

Thus, according to Van Kauwenbergh (2006), the enormous potential in terms of coal, hydrocarbon and natural gas in Africa represented 8%, 9% and 6% of the world's reserves at one point in time. These resources can be used for the industrial production of nitrogen (N) for plants. Large deposits of hydrocarbon and natural gas exist in the coastal zones of West Africa. Large deposits have also been recently discovered in continental countries such as Niger, Mali, Chad, etc.

Regarding potassium (K), two important deposits exist and are exploited in the Democratic Republic of Congo and in Ethiopia/Eritrea. Egypt and Morocco also have potassium deposits. According to Van Straaten (2011), sources of K exist in Togo, but they have low solubility. The same author reviews the sources of sulfur (S) other than organic matter, which exist in Africa. Deposits of elementary S are limited; they are found in Mauritania and Egypt. On the other hand, the sulphated form (gypsum) is widespread in Africa, notably in Mali, Mauritania, Niger, Nigeria and Chad. It should be noted that phosphogypsum is a by-product of phosphate industries in Senegal. The sulphides exist on the continent in the form of pyrite and/or chalcopyrite and are associated with other minerals such as gold or zinc. This source is often used for the production of sulfuric acid which is used for the production of soluble phosphate fertilizers. Despite these important sources of sulfur in Africa, they are not exploited for agricultural production.

Sources of calcium (Ca) and magnesium (Mg) also exist in Africa, in the form of calcium and/or magnesium carbonates. But the minerals containing these two elements, which are very important for soils and plants, are used more for the production of cement and tiles than for agricultural production.

Phosphate rocks (PR) deposits, a source of phosphorus for crops, exist in Africa and have been the subject of numerous studies since the beginning of the twentieth century both for their direct application and for the improvement of their agronomic efficiency (association with organic matter, partial acidification, PR solubilizing bacteria, use of mycorrhizal fungi, soil management methods, etc.). The results of these studies have often been a subject of controversy because of the complexity of phosphate rocks but also of the soils in which they are used (Hammond 1978). The following section of this document presents the major results achieved in the agricultural use of phosphate rocks with a view to promoting their use in the formulation of fertilizer formulas but also in the restoration of soil fertility.

9.4 West Africa's Phosphate Rocks as Inexpensive Source of Phosphorus in Fertilizer Recommendation Formulas

Africa has 80% of the world's phosphate rock reserves (Van Straaten 2011), which can be inexpensive sources of phosphate fertilizers locally available for crops. Figure 9.6 and Table 9.3 show respectively the localization of phosphate rock deposits in Africa and those existing in West Africa with their reserves, their P_2O_5 contents and their exploitation status.

These reserves are estimated at 1 million tons at 32% P2O5 for Rambuta reserves in Liberia; 200 million at 23% P2O5 for the Tapoa deposits in Niger. Some of these deposits are commercially exploited. These include the deposits of Hahotoé and Kpogamé in Togo, and Taïba and Thiès in Senegal. The deposits of Kodjari in Burkina Faso, Tilemsi in Mali and Tahoua in Niger are exploited through traditional mining, especially for local consumption. Johnson (1994) has identified over 20 other deposits in West Africa which are not yet exploited. Despite the wealth of West African countries in phosphate rocks, these countries, paradoxically, import phosphate fertilizers for political, economic and technical reasons.

9.5 Use of West Africa's Phosphate Rocks

Due to the presence of important deposits with interesting grades in sub-Saharan Africa, phosphate rocks constitute a valued local source of phosphorus for the countries that have them. However, it should be pointed out that virtually all phosphate rocks in West Africa have PO4/CO3 $>$ to 5 ratios making them unreactive or slightly reactive phosphates. Chien (1977) showed that the solubility of phosphate rocks in ammonium citrate is directly correlated to this PO4/CO3 ratio. Table 9.4 gives the percentages of solubility as well as the PO4/CO3 ratios of some of these phosphate rocks. According to Diamond (1978) cited by Bationo (2008), the fitness of phosphate rocks for direct application in agricultural

Fig. 9.6 Phosphate rock deposits in Africa (Source: Van Kauwenbergh 2006)

production is said to be high when the solubility in ammonium citrate is > 4%; it is average when this value is between 3.2 and 4.5%; it is low when the solubility is <2.7. On the basis of this classification it can be said that only the phosphates of Tilemsi and Sokoto have an average reactivity.

Given the complex biogeochemical cycle of phosphorus, there are several models for the representation of soil phosphorus flows and stocks. According to the model proposed by Banque Mondiale et al. (1994) and shown in Fig. 9.7, three major forms of phosphorus can be distinguished: agricultural phosphorus, capital phosphorus and inert phosphorus. The proportions of these three forms depend on many factors, including the type of soil, the degree of alteration of the substratum, the climate, and the importance and nature of the mineral colloids (clays).

Table 9.3 Major phosphwithe rock deposits in West Africa

Localiswithion	Reserves in millions of tons	Exploitwithion stwithus
Benin		
Mékrou	5 with 18% de P_2O_5	Unexploited
Pobé	–	Unexploited
Burkina Faso		
Kodjari	103 with 18–23%P_2O_5	Artisanal mining
Arly	4 with 15–32% P_2O_5	Unexploited
Guinea Bissau		
Farim-saliquinhe	112 with 30% P_2O_5	
Ghana		
Sekondi		Unexploited
Liberia		
Bambuta-Bomi Hill	1 with 32% P_2O_5	Artisanal mining
Mali		
Tilemsi	20 with 15–32% P_2O_5	Artisanal mining
Assakerei	–	Unexploited
Mauritania		
Bofal-Loubboira	100 with 19–20% P_2O_5	–
Niger		
Askia-Tinamou	–	–
Tahoua	5 with 25% P_2O_5	Artisanal mining
Tapoa	200 with 23% P_2O_5	Unexploited
Nigeria		
Abeokuta	–	–
Sénégal		
Taiba	100 with 18–39% P_2O_5	1,5 millions of t/an
Thiès	100 with 28% P_2O_5	0,5 millions of t/an
Pire Goureye	25 with 34%P_2O_5	–
Mwitham	36 with 28% de P_2O_5	Unexploited
Togo		
Hahotoe	130 with 28% P_2O_5	2 millions of t/an
Bassar	10 with 38%P_2O_5	Unexploited

Source: McClellan and Notholt (1986) and Truong (1989)

Table 9.4 PO_4/CO_3 ratios and % of solubility in ammonium citrate of some phosphate rocks of West Africa

Phosphate Rocks	PO_4/CO_3	Solubility (% P_2O_5)
Kodjari	23,00	1,9–2,7
Parc W	15,20	1,4–2,8
Hahotoe	12,30	2,5–3,2
Tahoua	4,88	1,9–3,6
Tilemsi	11,20	4,1–4,6
Sokoto	11,50	3,2–3,7

Source: Bationo (2008)

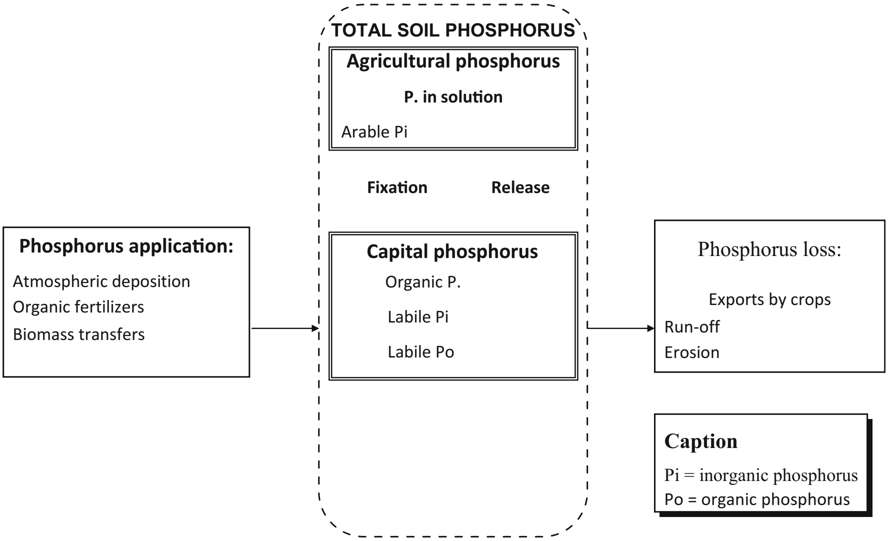

Fig. 9.7 Sources, flows and stocks of phosphorus in soils Banque Mondiale et al. (1994)

Agricultural phosphorus is the phosphorus available for crop production during a crop cycle. It is composed of phosphorus in solution and available phosphorus. The capital phosphorus is, by analogy with the management of farms or companies, the "business assets", the reserve or even the phosphorus stock. This stock supplies the agricultural phosphorus pool.

Therefore it appears clearly that the application of phosphate rocks, especially those with slow reactivity, will influence the "capital" phosphorus rather than the "agricultural" phosphorus.

The ability of phosphate rocks to supply phosphorus to plants depends on several factors including the physical and chemical characteristics of the ore, soil properties, climatic conditions, agricultural practices, cropping systems and plant type. Figure 9.8 shows the factors involved in the solubilization of phosphate rocks.

Numerous studies have been carried out in many West African countries to determine the agronomic efficiency of phosphate rocks and the best methods for their use (Truong et al. 1978; Truong 1989; Bationo and Mokwunye 1991; Bationo et al. 1994; Bationo and Kumar 1999). These studies were carried out through a range of methods including solubility tests in different reagents, incubations of different soil types, controlled pot experiments, research station experiments. Multilocal on-farm experiments were carried out taking into account different pedoclimatic conditions and cropping systems, and different cultivation practices. Most of these studies show that despite the low reactivity of most phosphate rocks in West Africa, they can contribute to improve crop yields (Mokwunye 1996; Mokwunye and Bationo 2011).

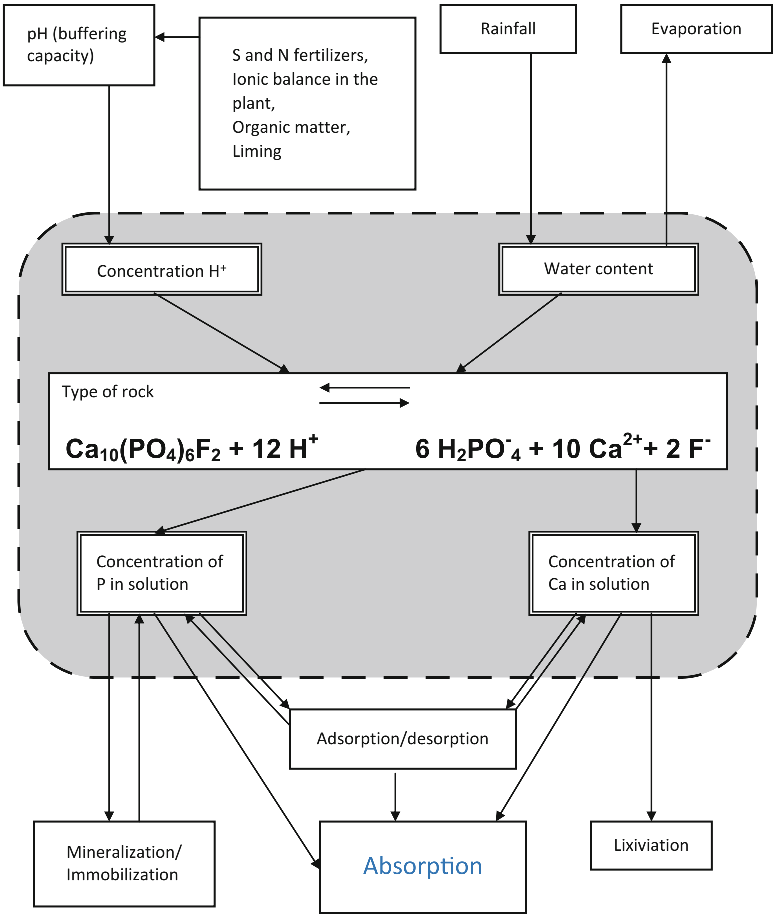

Fig. 9.8 Factors limiting the solubilization of phosphate rocks in soils (in the dotted area) and variables (outside the dotted area) influencing these factors (Source: Adapted from Bolan and Hedley 1990)

9.5.1 Use of Phosphate Rocks for Crop Fertilization in Niger

Numerous studies have also been carried out in Niger by the team led by André Bationo and his collaborators. Thus, the agronomic efficiency of Tahoua phosphate rocks (TPR) when combined with nitrogen was demonstrated. The data in Table 9.5 show that phosphorus application increases cowpea residue yields by 930 kg ha^{-1}. This increase is 765 kg ha^{-1} with the application of the same amount of P from the TPR. On the contrary, there is no difference between the sources of P on grain yields of millet in Gaya (685 and 665 kg ha^{-1}, respectively). It is noted that the

Table 9.5 Effects of combinations of different sources of phosphorus on grain yields of millet and residue yields of cowpea

	Karabedji		Banizoumbou
	Millet	Cowpea	Millet
Treatments	Grain yield	Residue yield	Grain yield
1 Absolute control	255	2250	276
2 30 kg N ha^{-1}	435	3031	432
3 12 kg P ha^{-1}	600	3594	708
4 12 kg P ha^{-1} PRT + 30 kg N ha^{-1}	520	4000	417
5 9 kg P ha^{-1} PRT + 3 kg P + 30 kg N	810	4531	583
6 6 kg P ha^{-1} PRT + 6 kg P + 30 kg N	893	4906	625
7 3 kg P ha^{-1} PRT + 9 kg P + 30 kg N	973	5438	760
8 12 kg P ha^{-1} + 30 kg N	708	4125	708
Standard deviation	24	135	59
CV	7%	7%	21%

Source: Bationo (2008)

combination TPR (50%) with soluble phosphate (50%) enables to obtain a yield of 770 kg ha^{-1}.

Bationo (2008) reported the results of its research in three agroecological zones of Niger, concerning the agronomic efficiency of the TPR and the Kodjari phosphate rocks (KPR), compared to SSP. The results achieved indicate that the agronomic efficiency values of the TPR were higher on millet than on legumes. Regarding millet grain yield varied from 63% to 80% and from 60% to 68% for the total production of biomass. For cowpea, it was between 42% and 73% for the production of residues and 52% to 72% for the total production of biomass. Whatever the site, the agronomic efficiency of the TPR is typically higher than that of the KPR. Similarly, the effects of two sources of P (PRT) and triple superphosphate (TSP) on yields and P use efficiency (PUE) by rice (Table 9.6). It was found that the highest PUE value (89 kg grain/kg P) was achieved with the TPR rate of 26 kg P ha^{-1}. With the triple superphosphate, the highest PUE (64 kg grain kg^{-1} P) was achieved with the rate of 22 kg P ha^{-1}.

The phosphate rocks of Kodjari (KPR) and those of Tahoua (TPR) were also evaluated by Bationo et al. (2011), through two modes of application, broadcast application (B) and localized application per pocket (P). On millet grain production, P use efficiency (PUE) from broadcast application of simple superphosphate (SSP) at the rate of 13 kg P ha^{-1}, was 26 kg kg^{-1} P. The efficiency of SSP application per pocket at the rate of 4 kg P ha^{-1} was 98 kg kg^{-1} P and 142 kg kg^{-1} P with the NPK blend applied per pocket. With broadcast TPR, the PUE was only 10 kg kg^{-1} P to reach 35 kg kg^{-1} P when the complex NPK fertilizer was applied per pocket, in addition to the TPR at the rate of 4 kg P ha^{-1}. For the production of cowpea residues, PUE values with broadcast SSP and NPK complex were 96 and 163 kg kg P^{-1} respectively. However, their application per pocket at the rate of 4 kg P ha^{-1}

Table 9.6 Effects of different rates of two phosphorus sources on rice yields and on phosphorus use efficiency (PUE)

Sources of P	P Rates (kg ha^{-1})	Grain yield (kg ha^{-1})	PUE Kg grain kg^{-1}P
PRT	0	1740	–
	26	4057	89
	39	4147	62
	52	4525	54
	65	5458	57
TSP	78	4853	40
	22	3150	64
	44	4222	56
	65	3810	32

PRT Phosphate rocks of Tahoua; *TSP* triple superphosphate

Table 9.7 Effects of sources and modes of P application on yields and P use efficiency for millet and cowpea in Karabedji, Niger

Treatments	Millet		Cowpea	
P Sources and application modes	Grain yield (kg ha^{-1})	PUE (kg kg^{-1} P)	Residues (kg ha^{-1})	PUE (kg kg^{-1} P)
1 Absolute control	444		1781	–
2 SSP (V)	776	26	3031	96
3 SSP (V) + SSP (V)	1151	42	4063	134
4 SSP (P)	834	98	3188	352
5 15–15-15 (V)	980	41	3906	163
6 15-15-15 (V) + 15-15-15 (P)	1510	63	5313	208
7 15-15-15 (P)	1010	142	3875	523
8 PRT (V)	569	10	2344	43
9 PRT (V) + SSP (P)	923	28	3000	72
10 PRT (V) + 15–15-15 (P)	1043	35	3625	108
11 PRK (V)	569	10	2375	46
12 PRK (V) + SSP (P)	1005	33	3094	77
13 PRK(V) + 15-15-15(P)	1094	38	3625	108
SE	28		167	
CV	6%		10%	

SSP simple superphosphate, 15-15-15: N_2 P2O5 K_2O complex fertilizers; *TPR* Tahoua Phosphate rocks; KPR: Kodjari Phosphate rocks; *B* Broascast application (13 kg P/ha); *P* Application per pocket (4 kg P/ha); *PUE* Phosphorus use efficiency (Grain yield/kg P applied)

gave PUEs of 352 and 523 kg kg^{-1} P. These data clearly show that localized application per pocket allows to improve PUE and that localized application of small amounts of soluble phosphate can also improve the agronomic efficiency of phosphate rocks (Table 9.7).

Table 9.8 Effect of Burkina Faso phosphate rocks combined with manure on soil chemical characteristics in Saria, Burkina Faso

Treatments	pH Eau	C tot. (%)	N tot. (%)	P tot. (mg kg^{-1}	Pav. (mg kg^{-1})	Ca cmol kg^{-1})	Mg cmol kg^{-1})
Absolute control	4.5	1.17	0.42	197	1.42	1.67	0.34
NPK disseminated	4.2	0.21	0.20	198	3.40	1.29	0.23
BP yearly	5.0	0.21	0.19	252	4.78	2.15	0.34
BP yearly + manure	4.8	0.28	0.17	241	6.79	2.42	0.38
BP correction + BP yearly	5.0	0.20	0.14	215	5.71	2.16	0.38
BP correction + BP yearly + manure	5.2	0.25	0.09	222	6.30	2.16	0.31
Initial soil (1982)	5.5	0.82	0.21	–	–	1.70	0.68

Source: Lompo et al. (1994)

9.5.2 *Use of Phosphate Rocks for Crop Fertilization in Burkina Faso*

Several studies on Burkina phosphate rocks, known as Burkinaphosphate (BP), show that it improves crop production as well as the physical, chemical and biological properties of soils (Hien et al. 1992; Lompo 1993; Bationo et al. 1987; Lompo et al. 1994; Bonzi et al. 2011). As shown in Table 9.8, BP (i) improves soil structure when combined with manure; (2) stabilizes cereal production when applied as basal dressing combined with manure, with increased levels of total P, Ca and magnesium in soils; (3) stimulates the activity and proliferation of microbial strains contributing to the decomposition of organic substrates.

In addition, a number of multi-site and multi-year trials were conducted to assess the agronomic efficiency of BP on different crops compared to other sources of phosphorus available in Burkina Faso.

9.5.3 *Effects of Phosphate Rocks on Irrigated Rice*

The works of Bado (1991) in the irrigated area of the Kou Valley in southwestern Burkina Faso allowed to compare BP with TSP (triple superphosphate) over three (03) cropping seasons. The results are given in Table 9.9.

The relative efficiency ratios of BP versus TSP on irrigated rice are shown in Table 9.10.

Table 9.9 Yields (kg ha^{-1}) of paddy rice - Kou Valley, Burkina Faso

	Burkina phosphate (BP)			Triple Super Phosphate (TSP)		
Kg P_2O_5 h_a^{-1}	HS88	DS88	HS89	HS88	DS89	HS89
0	4975	944	1020	4975	994	1020
30	5122	1216	1023	4634	1726	1676
60	5131	1461	1214	4979	1390	1389
90	4807	1817	1133	4556	1707	1268

HS humid season; *DS* dry season

Table 9.10 Relative efficiency ratios of phosphate on irrigated rice in the Kou Valley in Burkina Faso

P_20_5	Humid season 1988	Dry season 1989	Humid season 1989	TSP
Kg ha^{-1}	BP	BP	BP	
30	114	7	40	100
60	110	133	78	100
90	124	121	80	100

Bado (1991)

Paddy rice yields, relative efficiency ratios, and production functions linking phosphate to grain yields led to the following conclusions:

- BP is not efficient on irrigated rice at rates below 500 kg ha^{-1};
- BP is more efficient than TSP when applied at high rates.

The inefficiency of low rates of BP on irrigated rice would be related to the type of soils found in these areas. Indeed, these are hydromorphic soils, very rich in clays and hydroxides, thus raising their binding capacity. Consequently, much of the soluble P would be very quickly fixed in the soil and temporarily or permanently escaped from the plant. Thus, the small amounts of soluble P contributed by BP are totally fixed, hence its inefficiency. At high rates, BP can saturate the binding sites and the insoluble P being solubilized remains available for rice. Indeed, in this hydromorphic environment, the presence of sulfur ions and other hydroxides and the continuous dissolution of carbon dioxide (carbonic gaz) from the air in water create favorable conditions for the attack and solubilization of BP. To that must be added the dissolving capacity of irrigation water reported by Kouma (2000). BP is more suitable for acid hydromorphic soils at the rate of 500 kg ha^{-1} as basal dressing in the first year plus 200 kg ha^{-1} as supplementary annual dressing in the other years, the soluble sources being exposed to P fixation.

9.5.4 Effects of Phosphate Rocks on Rainfed Rice

The trials on rainfed rice carried out on ferralitic soils slightly acidic yielded interesting results (Table 9.11).

Table 9.11 Effect of phosphates on yields of paddy rice in ferralitic soil at Farako-Bâ (kg ha^{-1}) in Burkina Faso

	BP		TSP	
P_20_5 (kg ha^{-1})	1988	1989	1988	1989
0	2533	1643	2533	1643
30	2735	2269	2799	2065
60	3301	2562	3054	1593
90	3014	2387	3128	2471

Source: Bado (1998)

Table 9.12 Synthesis of three (03) years of on-farm trials in several sites across Burkina Faso

	Maize 50 sites		Millet 52 sites		Sorghum 127 sites	
Treatments	Grain yield. kg ha^{-1}	Eff. ratio (%)	Grain yield kg ha^{-1}	Eff. ratio (%)	Grain yield kg ha^{-1}	Eff. ratio eff. %
Absolute control	1020	–	542	–	812	–
BP	1759	79	723	55	1095	63
NPK	1973	100	869	100	1260	100

Source: Hien et al. (1992)

These results show that BP is as efficient as TSP in these soils. The recommended rate is 600 kg ha^{-1}. BP is highly efficient on rainfed rice in acidic ferralitic soils at an optimal rate of 600 kg BP ha^{-1} as basal dressing in the first year plus 300 kg BP ha^{-1} as supplementary annual dressing in subsequent years.

Numerous trials with BP as a source of P were carried out throughout Burkina Faso as part of the Food Crop Fertilizers Project for three successive years. Table 9.12 summarizes the results of these trials conducted in three agro-ecological zones:

A: annual rainfall <600 mm
B: $600 <$ annual rainfall <800 mm
C: rainfall $>$ 800 mm

The agronomic efficiency ratio (Eff. Ratio) is evaluated in relation to NPK as the source of soluble P. The main conclusions that can be drawn from these on-farm trials are the following:

- BP is efficient on maize in the rainiest areas and on millet, a plant with high root density;
- With sorghum, the responses to the BP-based formula are variable depending on the area and could be rather based on pH and soil P deficiency levels.

9.6 Agronomic Performance of Some Partially Acidified Phosphate Rocks of West Africa

The low reactivity of most phosphate rocks in West Africa limits their agronomic efficiency when used directly in annual fertilization on annual crops. Partial acidulation, which aims to improve phosphate solubility, consists in attacking the minerals by mineral acids (H_2SO_4, H_3PO_4, HCl). This attack is called partial because the amount of acid used lower than that required for the production of TSP (in the case of sulfuric acid) SSP (in the case of phosphoric acid) for which the attack by acids is total. A variety of partially solubilized phosphate rocks having different compositions and agronomic efficiencies are thus obtained.

Paul (1998) carried out an important research work on the characterization and evaluation of partially acidified phosphate rocks from Anecho (Togo), Tilemsi (Mali) and Kodjari (Burkina Faso). He reported the results of the evaluations of these products in vase vegetation and on farms managed by IFDC and IRAT.

For Togo phosphate rocks, efficiencies on crops of products obtained through partial acidification, compared to TSP or SSP are between 51% and 90% depending on the percentage of acidification and the type of acid used. On-farm trials comparing the effects on different crops (groundnut, cotton and maize) of different sources of P (including NPK complex, phosphates solubilized at 50% with H_2SO_4), show that the yields obtained with the soluble P source are higher than those obtained with the partially solubilized phosphate. The efficiency ratios for soluble phosphate are 68% for cotton, 86% for maize and 90% for sorghum and groundnut (Truong 1984).

For the Mali phosphates, the results obtained by Samaké (1987) indicate equivalence between the phosphate rocks of Tilemsi acidified at 27.3% with H_3PO_4 and SSP.

Regarding the Burkina phosphate rocks, trials carried out under the Food Crop Fertilizers Project focused on the comparison between TSP and the BP partially solubilized by a mixed attack (H_2SO_4 + H_3PO_4). The agronomic results show that sometimes partially acidulated phosphate rocks are practically equivalent to superphosphates.

9.7 Conclusion and Perspectives

Considerable amount of research works have been carried out on West Africa's phosphate rocks. They have demonstrated the relative agronomic efficiency of these phosphate rocks despite their low reactivity. Phosphate rocks are well suited for improving soil fertility by enabling to recharge the pool of "capital P", which in turn will feed the pool of agricultural P as the plants feed on this agricultural P. These two pools are the main sources not only for supplying P to crops but also for correcting soil P deficiencies in West Africa. The replenishment of P stocks by direct application of phosphate rocks is a very profitable investment, especially when PR applications are combined with organic matter supplies, water harvesting and other nutriment management techniques, and good agricultural practices.

Despite this scientific evidence, most phosphate rock deposits in West Africa are not exploited. Policy makers and fertilizer manufacturers are challenged to take account of these agro-mineral resources, including the important potential of the sub-region regarding dolomite and sulfur. Pre-feasibility studies for phosphate rock- based fertilizer plants exist for some of the natural phosphate deposits. The construction of fertilizer formulation plants should provide a basis for the establishment and implementation of public-private partnerships. The issue of land tenure security is also an issue that policymakers should address to promote the adoption of technologies and innovations by farmers; especially regarding land recapitalization (e.g. through the large-scale use of phosphate rocks).

Many phosphate rock deposits remain poorly known in terms of their characteristics and agronomic values. Chude et al. (2008) suggest the following research lines: (1) better mineralogical characterization, (2) evaluation in different ecologies, (3) better understanding of constraints to adoption by agricultural producers, (4) defining management options to improve PR efficiency, and (5) assessing the environmental effects associated with heavy metal and radioactive elements contents. These suggestions also hold for other phosphate rock deposits in West Africa. This should be combined with efforts to be made by research and development entities to include these phosphate rocks in fertilizer recommendations for crops. The role that farmers must play individually or through their organizations is also fundamental. Support from the Government and its technical and financial partners is essential, but their commitment to the transformation of agriculture is equally essential.

As long as farmers are confident that they will have access to product, fertilizer and financing markets, they will be willing to produce more not only to ensure their food self-sufficiency and that of their countrymen, but also to further contribute to the economic development of their country's economy. For this, political decision-makers and technical and financial partners need to put agriculture at the center of their agenda and the various national and regional policies, strategies and programs developed must be effectively operationalized.

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Chapter 10
Fertilizer Recommendations for Maize and Rice Based on Participatory Nutrient Omission Trials

Adonko F. Tamelokpo

Abstract The main constraint of agriculture in Togo is soils' low content in nutrient and organic matter. Inappropriate land use, poor management and limited use of mineral fertilizers have led to the degradation of agricultural lands. Consequently, crops yields are significantly and continuously declining. For crops such as maize and rice, yields are lower than 1.5 t/ha. Even fertilizers applications on these crops are inefficient because fertilizer recommendations dating back to over 40 years are obsolete and inappropriate. Existing fertilizer types and recommended rates have become inappropriate due to continuous nutrient exports by crops without their return to the soils. Moreover most of these recommendations have been developed without taking into account the specificities of the various agro ecosystems, to be applied uniformly throughout the whole country.

Given this situation, many research works were carried out on maize and rice fertilization.

Interesting results were achieved but not disseminated due to low level of collaboration between research, extension, farmers and decision makers. To address this issue, from 2011, Participatory Nutrients Omission Trials (PNOT) were conducted in the five regions of Togo by IFDC and partners, then from 2012 to 2014 in the framework of the Project to Support Agricultural Development in Togo (PADAT) involving 16,000 farmers and 111 technicians and specialists trained on Integrated Soil Fertility Management (ISFM). It was concluded that about 89% of soils are low in nitrogen identified as the major limiting nutrient to crop yields in PADAT areas. The main fertilizers available in the country are NPK (N -15%, P_2O_5- 15%, K_2O -15%) and Urea (46% of N). The conclusion was that, in the short term, farmers should be advised to use 150 kg of NPK + 150 kg of Urea per hectare on maize and rainfed rice. However, it is necessary that single fertilizers such as Urea, TSP, and K2SO4 be available for participatory soil fertility diagnosis (PSFD) to facilitate sound decision making. In view of the outcomes, the diammonium phosphate (DAP) could be recommended to maize and rice

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producers, as most soils have sufficient levels of potassium. The PSFD should be a continuous process and results widely disseminated to help farmers correct soil nutrient deficiencies as soon as they appear in time and place.

Keywords Integrated management • Soil fertility • Limiting factor • Participatory nutrient omission trial • Diagnostic • Nitrogen • Phosphorus • Potassium • Yields

Contents

10.1 Introduction

In sub-Saharan Africa in general, and particularly in Togo, agriculture remains the principal source of income, food and energy for a large proportion of the population, but it is unable to cover all needs. This situation is caused by the combined effects of soil degradation and the very low use of external inputs, mainly fertilizers. Indeed, the soils in the sub- region are poor and fragile. This, combined with other factors such as the lack of access to finance, innovation and markets, has led to the emergence of aggressive cash crop farming. The main constraint to crop productivity in Togo is the soils low content in mineral and organic nutrients. Inappropriate land use, poor management and limited use of mineral fertilizers have accelerated the degradation of agricultural lands. This has resulted in significant and continuous decline in maize and rice crop yields, among others. However, most fertilizer formula recommendations for these crops, which date back to over 40 years, are obsolete and inappropriate. Existing fertilizer types and recommended rates have become inappropriate due to continuous nutrient exports by crops without their return to the soils. Moreover most of these recommendations have been developed without taking into account the specificities of the different agro ecosystems, to be applied uniformly throughout the whole country.

Existing fertilizer types as well as recommended rates have become inappropriate due to continuous nutrient exports by crops without their return to the soils. Moreover, these recommendations have been developed without taking into account the specificities of the various agro-ecosystems, to be applied uniformly throughout the country. In these circumstances, farmers cannot optimize returns on fertilizer investments, especially when these fertilizers do not take into account the factors which limit yields on their soils. Indeed the involvement of farmers and agricultural extension workers in the participatory soil fertility diagnosis is essential to ensure specific and appropriate decisions concerning the fertilization of maize and rice. After a brief historical overview of fertilization initiatives in Togo, the present study shall discuss a case of fertilizer recommendation for maize, based on participatory nutrient omission trials.

10.2 Objectives of the Study

- Contributing to poverty reduction, and improvement of food security and land resources quality for men and women farmers through Integrated Soil Fertility Management (ISFM)
- Strengthening farmers' capacities through the Farmer Field School approach (FFS), the promotion of participatory learning, and the development and implementation of ISFM options for maize and rice to improve yields

10.3 History of Soil Fertility Improvement Activities and Recommendations

In Togo, the practice of fallowing, even for short periods, is no longer possible in most regions due to high population density; particularly in the Maritime Region (350–500 people per square km), the Kara region and the Savannah region (30–300 people per square km),). The replacement of production systems based on long fallow periods by the continuous cropping system caused the disruption of the balance between the quantities of nutrients entering the agro-ecosystem and those exiting in the form of N, P and K exports by the crops.

The fertility balance of the soils of Togo (IFDC 1990) over the period 1984–1987 revealed average annual losses in the order of 18 kg N, 5 kg P and 15 kg K per hectare. An estimate of the nutrient losses projected to the year 2000, gave the following figures: 21 kg N, 7 kg P and 19 kg of K per hectare per year. These figures clearly show that since well before 1990, soil reserves of N, P and K are gradually becoming depleted, as soils are exploited without adequate precautions.

For over 40 years, research has been carried out with a view to improving soil fertility. Preliminary studies on the fertilization of cereals have shown that soils are generally low in major nutrients such as N, P and K. On the basis of this finding a fertilization formula was developed for cereals in 1975 by the mission of support to accompanying research IRAT/GERDAT (1975 in Douti P.Y. 1992). This formula, which was popularized in a uniform manner throughout the country is 150–200 kg/ha of NPK 15-15-15 + 50–100 kg/ha of urea. This allows to apply 53 76 kg of N, 30 kg of P2O5 and 30 kg of K2O per hectare to the soil.

The SAFGRAD project carried out fertilization trials in the regions of Kara and Savanes. In this framework, an economic fertilization system was developed for the rotation cotton-maize-groundnut-sorghum. This led to the following recommendations: for maize 100 kg of 15-15-15 + 50 kg of urea per hectare, for groundnut 100 kg of TSP and for sorghum 50Kg of 15–15-15.

From 1966 to 1970, the Institute for Research on Cotton and Textiles (IRCT) carried out studies relating to the development and correction of mineral deficiencies by region, fertilizers rates, nitrogen fertilization and phosphate fertilization. The results showed that cotton yields fall from 20% to 50% in the absence of phosphorus in mineral fertilizers.

IFDC, in collaboration with the National Soil Institute (INS), within the framework of the West African Fertilizer Management and Evaluation Network (WAFMEN), has carried out work on the comparison of different rates and forms of nitrogen fertilizers, the effects of crop residues on nitrogen efficiency, nitrogen fertilizer application methods, and nitrogen dynamics in the soil-plant-fertilizer system using N^{15}. The results obtained showed that the supply of nitrogen triples maize yields on all sites compared to the control (Bationo & Mukwunye 1991a). Urea is the best performing form of fertilizer; the best application method is that of buried bands. Soil nitrogen deficiency was corrected with nitrogen rates between 60 and 120 kg/ha under the soil and climate conditions of the study areas. It was also shown that only 30%–40% of nitrogen contributes to plant development. The losses due to volatilization were of 25–30% depending on the sites. Above the rate of 120 kg/ha, nitrogen efficiency decreases.

Taking stock of the achievements of fertilizer research in Togo during the period 1974–1988, P. DOUTI highlighted three deficiency zones in a nutrient decreasing order as follows:

- Zone 1: *Regions of Savanes, Kara and Plateaux-West: Phosphorus-Nitrogen-Potassium*
- Zone 2: Regions of Central and Plateaux - East: Nitrogen-Phosphorus-Potassium
- Zone 3: Maritime Region: Potassium-Nitrogen-Phosphorus

In 1988, IFDC, in collaboration with Togo, Ghana and Mali, studied the viability of fertilizers and soil amendments as an investment to maintain and restore soil fertility.

WAFMEN, in collaboration with INS, carried out exploratory trials on phosphorus in farmer's field from 1989 to 1992 in the Kara region, from 1992 to 1995 in the Maritime region. The aim was to validate in farming environment the results achieved with phosphorus in research stations in each of the regions under study. The results showed that the soils of the Kara region are very deficient in phosphorus, whereas in the Maritime region crop responses to phosphorus are not the same everywhere. It was confirmed that, in general, partially acidulated phosphate rock

(PAPR50) had effects equivalent to those of the single superphosphate (SSP) in each region.

Starting from 1996, a study on participatory management of soil fertility in the farming environment was carried out with the support of International Fertilizer Association (IFA). This study aimed to strengthen linkages between farmers, fertilizer suppliers, researchers and extension workers. The outcome was the implementation of ISFM in the Maritime Region from 1998 to 2002 within the framework of the Village Development and Organization Project (PODV). It was demonstrated, from 1998 to 2002, that after a short mucuna fallow, the efficiency of fertilizers applied to maize increases (Fofana et al. 2002). From 2002 to 2006, IFDC's works have shown that the participatory diagnosis of soil capacity to supply N, P and K allows to formulate recommendations adapted to farmers' financial capacity to purchase fertilizers (Lamboni and Tamelokpo 2004)

In addition, the Maize-Mucuna-Cassava-Fertilizers (MMuCa-F) option developed through a participatory diagnosis of the fertility of ferrallitic soils in the Maritime region was validated in 2005 and 2006. It was recommended to alternate the following two options on plots previously amended at the rate of 300 kg.ha^{-1} of Togo Phosphate Rock (TPR):

- 100 kg of K_2SO_4 + 100 kg of urea on pure maize + mucuna
- 150 kg of K_2SO_4 + 100 kg of urea on maize and cassava

These new validated options enable to improve soil contents in potassium (83 kg.ha^{-1}), phosphorus (47 kg.ha^{-1}) and calcium (67 kg ha^{-1}) compared national practice.

These new options are more cost-effective than the conventional practice and the national practice.

Based on the research findings, improved technologies have been developed by research in the 1990s but improperly disseminated due to poor functional relationships between agricultural research and extension. Indeed, to devise solutions to address those gaps, a National Agricultural Services Support Program (PNASA) implemented by the Togolese government led to the creation of three agricultural structures within the Ministry of Agriculture, Livestock and Fisheries.

These are (1) the General Secretariat (GS), the administrative body responsible for coordinating and supervising the programs of the Ministry's central and external services, and public institutions under the authority of the Ministry; (2) the Institute for Consulting and Technical Support (ICAT), a semi-public company responsible for leading activities related to the promotion of the rural world through the professionalization of agricultural producers; and (3) the Togolese Institute of Agronomic Research (ITRA), a semi-public company engaged in research activities aimed at promoting agricultural production, particularly in the areas of plant, animal, fishery and forestry production, the environment as well as agricultural and food technologies.

Indeed, to cover the populations' needs in a secure and sustainable manner, the Togolese agriculture should effectively apply the available research results through the efficient operation of these structures. To this end, it is important to mobilize all existing resources, and combine efforts at national and international level to develop a national soil fertility management strategy. Such a strategy should focus on the use of local resources, the creation of functional linkages between research and extension, the involvement of farmers at all levels, the development of an incentive policy for food prices and support to agricultural producers through credit policy. This must be part of an integrated approach involving all the partners involved in the rural world: farmers, extension workers, NGOs, private sector, researchers, donors, decision-makers. This participatory model was tested from 2012 to 2014 through the implementation of the ISFM component of the PADAT project.

10.4 Materials and Methods

10.4.1 The Site

Togo is located in West Africa and bordered to the north by Burkina Faso, to the south by the Atlantic Ocean, to the east by Benin and to the west by Ghana with an area of 56,600 km2 for a population of 7 million inhabitants, of which 70% practice agriculture. The diet of the Togolese population is largely based on cereals, mainly maize. Maize, once exclusively cultivated in the southern regions of Togo, has now extended to the northern regions. If maize production in Togo was lower than 200,000 tons (DESA 1990), it increased, oscillating between 500,000 and 700,000 tons from 2006 to 2009. The rate of population growth is about 3%, agricultural production must keep up with this growth to meet the needs of the populations in a timely manner. However, it is shown that 89% of Togolese arable lands produce only between 0 and 1500 Kg/ha of grain maize and paddy rice. Improving this production level requires efficient use of mineral and organic inputs combined with soil and water conservation techniques and the use of improved seeds.

10.4.2 Rainfall

The rainfall pattern is bimodal in the South. The main rainy season begins in March and ends in July with maximum rainfall in June. The small rainy season begins at the end of September and ends in early November. The average annual rainfall is around 1200 mm.

In the North, the rainfall pattern is monomodal with a rainy season that begins in June and ends in October with maximum rainfall in August. The average annual rainfall of 1400 mm dropped considerably during the period of the study. Annual rainfall averages recorded by ICAT from 2012 to 2014 are presented in Fig. 10.1.

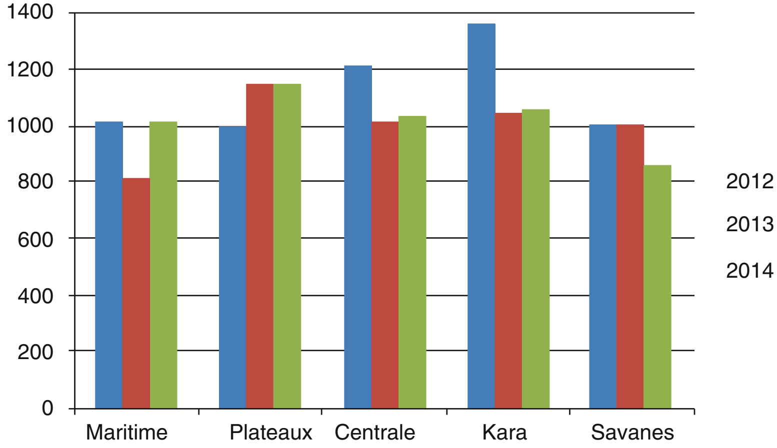

Fig. 10.1 Average rainfall per region from 2012 to 2014

This rainfall is highly variable, thus to better observe rainfall levels on the plots, and since rain gauges were not available on all sites, farmers were involved in the observations and were able to inform researchers and technicians about soil moisture content by systematically filling in the rainfall recording sheets available in the farmer field schools.

10.4.3 The Soils

The soil cover in Togo is characterized by several types of soil: Ferruginous (60%) on the granite-gneissic base consisting of granite, gneiss and quartzite covering two thirds of the territory (ADAM 1997). They are also encountered on the Birrimian base constituted of sandstone which covers the northeastern part of the country; the ferralitic soils largely represented by the “terre de barre” (10%), which occupy the southern part of the country. These soils are deeply altered, fragile and their nutrients contents are relatively low. They contain iron and aluminum oxides and hydroxides capable of giving them a soluble phosphorus sorption capacity. There are also soils with the hydromorphic characteristics of alluvial plains and lowlands, poorly developed soils and Vertisols. Soil analysis was not included in this work (Table 10.1).

Table 10.1 Details of the options selected by farmers following the participatory diagnosis

ISFM Plot	receives NPK 15 15 15 + Urea (ordinary urea or USG for rice) 46% N + TPR and/or a legume (mucuna, cowpea or soybean in relay, in catch cropping or in association); or + application of organic matter in pockets (poultry droppings manure . . .) It is only the improved farmer practice (FP).
FP Plot	(Local Farmer Practice) –this is the current farmer practice identified in the area which has been agreed upon with farmers after the participatory diagnosis. It is specific to the FFS concerned.
PSFD Plot	(Participatory Soil Fertility Diagnosis) – There, 5 elementary plots receive or not simple fertilizers N at 90 kg/ha in the form of urea (46% N); P at 20 kg/ha as TSP (46% P2O5) and K at 50 kg/ha as KC1 (60% K2O). Depending on the treatment, the combinations NPK, PK, NK and NP are made. An absolute control is the 5th treatment that is not fertilized. This allows to assess the present soil fertility status.
Validation Plots	These include the adapted option and the national fertilizer option which will receive NPK 15 15 15 and urea 46% N. The national option identified consisted in applying 300 kg of fertilizers at the rate of 200 kg of NPK 15–15-15 between 15 and 21 days after sowing (l^{er} application) and 100 kg of urea at stem elongation (2^{e} application). The adapted national option consisted in applying also 300 kg of fertilizers per hectare in the form of NPK 15–15-15 and urea but, at the rate of 150 kg of NPK + 50 kg of urea at the first application and 100 kg of urea at the second application. For rice, the second application is urea super granules. Expenses for purchased fertilizers in the national option and in the adapted option are equal; the prices of NPK and urea being the same.

10.4.4 The Crops

10.4.4.1 Maize *(Zea maiz)*

In Togo, the cultivated areas are steadily increasing. In the Maritime region and the Plateaux regions which have two rainy seasons, maize is grown twice a year. In the Central, Kara and Savanes regions, which have a single rainy season, maize is grown only once a year. The maize variety used is IKENNE. Among the varieties of maize disseminated in Togo it is one of the most widely used by farmers. Its vegetative cycle is 90 days. Its average size is 170 cm. The height of insertion of panicles is 140 cm while that of insertion of the cobs is 60 cm. It has good resistance to lodging, breakage and viruses as well as good drought tolerance. Its average productivity is 2.5 tons per hectare but can reach and even exceed 5.0 tons per hectare Adou Rahim (Alimi 2001). In pure culture, maize is sown with a spacing of 80 cm x 40 cm and two seeds per pocket. It can be cultivated in association with cowpea, soybean, or groundnut. The pockets are made manually using a hoe or a piece of wood specially cut for that purpose.

10.4.4.2 Rice *(Oriza sativa)*

The most common type of rice grown by smallholder Togolese farmers is the lowland rice. Rice farms are developed in boxes bordered by bunds for water retention (30–50 cm depth). The rice growing system is mainly rainfed in Togo. As a result, the risks of drought due to climatic abnormalities are high. Yields are therefore relatively low.

Average yields of upland rice are close to 0.9 t/ha. Yields above 3.5 t/ha can be achieved on fertile soils when the varietal quality and favorable climatic conditions are met. Rainfall conditions in Togo (800–1200 mm/year) meet the minimum (760–1270 mm/year) requirements for the normal development of most rainfed rice varieties. It is also recognized that it is possible to grow rainfed rice on soils with pH between 4 and 8 (Tropical agriculture 2nd edition 1979). Sahrawat and Jones (1995) pointed out that phosphorus deficiency is the main nutrient limiting the production of rice on the acidic highlands of West Africa. On these soils, reactions of the soluble phosphorus with aluminum oxides reduce its assimilability.

The amounts of fertilizers used for rice are the same as for maize. However, given the risk of nitrogen losses during the flooding of traps by rainfall, the use of urea super granules was tested to improve nitrogen efficiency. The advantage of this technique is related to the gradual solubilization of the granules buried in the soil compared to the prilled urea grains which dissolve as soon as they are applied to the wet soil. Techniques of rice rotation with legumes and organic and/or mineral nutrient sources are used under appropriate specific conditions. The variety of rice used is the IR-841. It is sown following a pattern of 25 cm x 20 cm and 3 seeds per pocket.

10.5 Case of Integrated Soil Fertility Management for Maize and Rice Under the Project to Support Agricultural Development in Togo (PADAT)

Integrated soil fertility management is based on participatory nutrient omission trials in farmer field schools (FFS). The main activities concern the training of stakeholders in the management and monitoring of plots, site identification and choice of options, ISFM learning sessions for farmers, rural information workshops covered by the media, data collection and their geographical projection on digital maps.

ISFM training activities and results

Maitres-formateurs	19
Facilitateurs (Conseillers)	92
Formateurs endogènes	1252
Producteurs	14962

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Fig. 10.2 Training results

10.5.1 *Stakeholder Training*

Stakeholders (extension workers, researchers and farmers) were trained on the use of participatory nutrient omission trials in order to identify the limiting nutrients to the production of maize and rice on their soils with a view to making appropriate decisions. The training of agricultural stakeholders aimed at setting up an ISFM team.

The training sessions were held in classrooms/or in farmers' fields on topics related to ISFM and the development of fertilizer options. A total of 19 trainers received these trainings and have trained 92 agricultural advisors who in turn initiated 1252 farmers as endogenous trainers to accompany 14,962 farmers members of 628 farmer field schools (Fig. 10.2).

10.5.2 *Identification of Sites and Choice of Options for Stakeholder Training*

Villages and farmer groups were identified at the end of the participatory diagnoses (PD) carried out in the areas selected by PADAT in the different regions: Maritime, Plateaux, Central, Kara and Savanes. These PDs allowed to create, from 2012 to 2014, 628 ISFM based-farmer field schools (FFS-ISFM); An ISFM- FFS is a group of 20 farmers on average who learn about IFSM on a demonstration plot and are prepared to take ownership and further disseminate the technical itinerary. During the PDs, systems and practices are identified with farmers for ISFM learning. The learning generally focuses on improving the options selected in the PDs and techniques for adapting them to farmers' specific conditions. Following the PDs, 14 options were identified by farmers with the support of facilitators (researchers and extension workers). A validation option and a participatory soil fertility diagnosis option are added to facilitate IFSM learning for farmers. The general list of options is as follows:

1. Maize + Mucuna + Fertilizers (MmuF) in rotation with maize + millet +fertilizers (MMaF)
2. Maize + Cassava + OM + Fertilizers (OM = compost or mucuna)
3. Cassava + Fertilizers
4. Maize + Mucuna in relay cropping +Fertilizers
5. Maize +Cowpea as catch crop + TPR + Fertilizers
6. Maize + Soya + TPR + Fertilizers
7. Maize + Squash as catch crop + Fertilizers
8. Maize + Sorghum + Fertilizers
9. Maize + Fertilizers in rotation with Sorghum + OM
10. Maize + OM + Fertilizers
11. Maize + Legumes + Sorghum +Fertilizers
12. Maize in pigeon peas alleys + Fertilizers
13. Maize + Groundnut +Fertilizers
14. Lowland rice + USG
15. Validation of option adapted by farmers
16. Participatory Soil Fertility Diagnosis (PSFD)

At least one of the proposed ISFM options (1–14) is installed depending on site-specific conditions and the choice of FFS farmers. These options are designed with farmers' participation, based on existing cropping systems, available local resources and fertilizers. Option 15 is installed in each FFS for demonstration to farmers and its comparison with farmer practice and the national option. It consisted in applying 6 bags of 50 kg of fertilizer at 11,000 FCFA per bag. Taking into account the types of fertilizer available in Togo and to facilitate adoption and/or rehabilitation of options, the use of NPK 15-15-15 and urea is an integral part of the ISFM option in the FFSs.

Depending on the conditions reported in the PSFD of the area concerned, NPK and urea may be supplied either in equal rates (150 kg NPK + 150 kg urea) or 200 kg NPK + 100 kg urea. Option 16 (DPFS) is installed in the ISFM-FFS to train farmers and facilitate their decision-making concerning the purchase and application of mineral fertilizers under their specific conditions. The purpose is to (i) facilitate the learning of farmers' observations on ISFM options and the options under demonstration for adjustment as required, (ii) facilitate farmers' adaptation of options and (Iii) generate information to feed the QUEFTS model for in-depth analysis and rapid extrapolation of recommendations.

10.6 General Protocol

The general protocol consists in introducing into the local agricultural practice identified in the (PD) innovations that can improve soil fertility and crop yields. The main indicator of soil fertility is the yield level that these innovations allow the crop to achieve. The protocol includes ISFM options, farmer practices (FP), participatory soil fertility diagnosis (PSFD) and validation (Table 10.2).

Each option is installed by farmers assisted by researchers and extension workers (Fig. 10.3). The installation takes into account the specific environment conditions that may guide ISFM learning by the local community. On sloped

Table 10.2 Selected ISFM options

ISFM Options		Nutrients (Kg/ha)			
No	Components	Designation	N		K
1.	Maize + Mucuna + Fertilizers (MMuF) in rotation with maize + Cassava + Fertilizers (MCaF)	MMuFxMCaF 60	90		TPR + 20
2.	Maize + Cassava + OM + Fertilizers (OM = compost or mucuna)	MMaE + OM^{a} 60	90		TPR + 20
3.	Cassava + Fertilizers	CaF	*90*	*10*	*19*
4.	Maïs + Mucuna in catch cropping +Fertilizers	MMuF	*90*	*10*	*19*
5.	Maize + Cowpea in catch cropping + TPR + Fertilizers	MCoF + TPR	*90*	*10*	*19*
6.	Maize + Soya + TPR +Fertilizers	MSoF + TPR	*90*	*10*	*19*
7.	Maize + Squash in catch cropping + Fertilizers	MCoF	*90*	*10*	*19*
8.	Maize + Sorghum + Fertilizers	MSorgF	*90*	*10*	*19*
9.	Maize + Fertilizers in rotation with Sorghum + OM	MSorgE + OM ^{a}	*90*	*10*	*19*
10.	Maize + OM + Fertilizers	MF + OM^{a}	*90*	*10*	*19*
11.	Maize + Legumes +Sorghum + Fertiizers	MSorgF + leg	*90*	*10*	*19*
12.	Maize in Pigeon Peas alleys + Fertilizers	MPiF	*90*	*10*	*19*
13.	Maize + Groundnut + Fertilizers	MGrF	*90*	*10*	*19*
14.	Lowland rice + USG	R + USG	*90*	*10*	*19*
15.	*Validation of option adapted by farmers*	*Val*	*90*	*10*	*19*
16.	*DPFS*	*DPFS*	*90*	*20*	*50*

**OM – 5 tons per hectare of compost or manure*

Nitrogen (N) is applied in the form of ordinary urea on maize, in the form of super granules on rice

Phosphorus is applied in the form TSP and TPR the first year, then replaced by TPR the following years

Potassium (K) is supplied in the form of potassium sulphate or potassium chloride. On the development and/or validation plots (Val), NPK 15-15-15 is used

Simple fertilizers are used on DPFS for Adaptation and/or specific reformulation of options

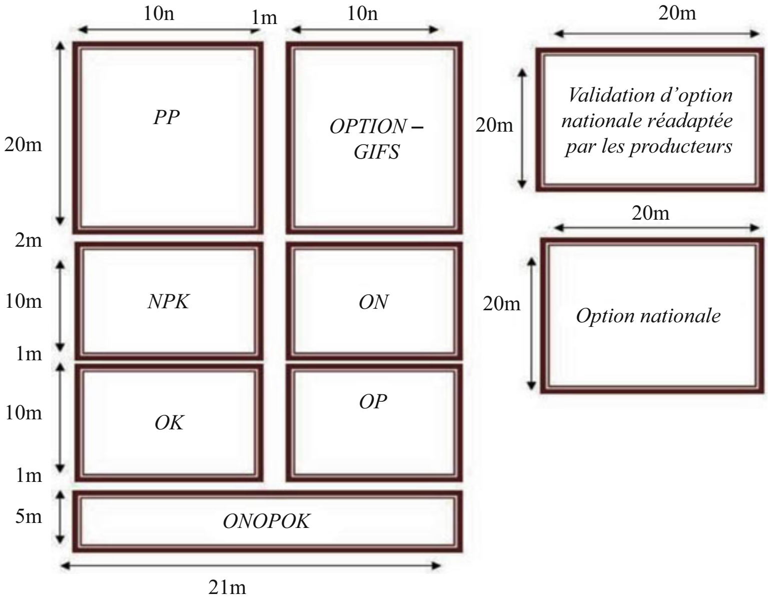


Fig. 10.3 Mechanism for setting up ISFM learning plots in the FFS

Table 10.3 FFS installed in 2014

Region	Maize	Rice	Total
Savanes	107	34	141
Kara	87	41	**128**
Central	100	14	114
Plateaux	98	16	114
Maritime	131	0	131
Total	**523**	**105**	**628**

terrain, anti-erosive structures are used. Organic matter (5 t/ha of compost or poultry droppings are used) or the quantities of locally produced mucuna, soybean or cowpea biomass are used buried in the ground (Table 10.3).

10.7 Data Collection

Data collection is organized by a team of technicians, farmers, endogenous trainers trained in ISFM implementation. Yields data are collected by endogenous technicians and trainers of each FFS.

The results of nutrient omission trials (PSFD) are analyzed at the MSTATC. The Map Info model is used for the geographical projection of yields achieved in the FFSs and the comparative analysis of yields per option in each FFS (Table 10.4).

Table 10.4 Learning results in FFSs in 2014

Regions	Number of FFS trainees		~ 553 Totaux55/]
	Men	Women	
Savanes	1767	1984	3751,555
Kara	1701	1046	2747,556
Centrale	1928	946	2874
Plateaux	1705	1114	2819,558
Maritime	1127	1644	2771,559
Total	8228	6734	14,962,560

10.8 Results and Comments

10.8.1 ISFM Learning

ISFM learning programs focused on improving the priority options identified during the participatory diagnoses carried out in villages. The configuration of options and cropping systems selected for ISFM-FFS is based on the major crops targeted by the PADAT project (maize, cassava and rice). Cropping system options selected for farmers' learning in the farmer field schools applied to ISFM-FFS are the following:

In the *Maritime region* – Maize in association with cassava, mucuna in relay to maize grown in rotation with the system maize – manioc in association;

In the *Plateaux region* – cropping systems based on maize and rice;

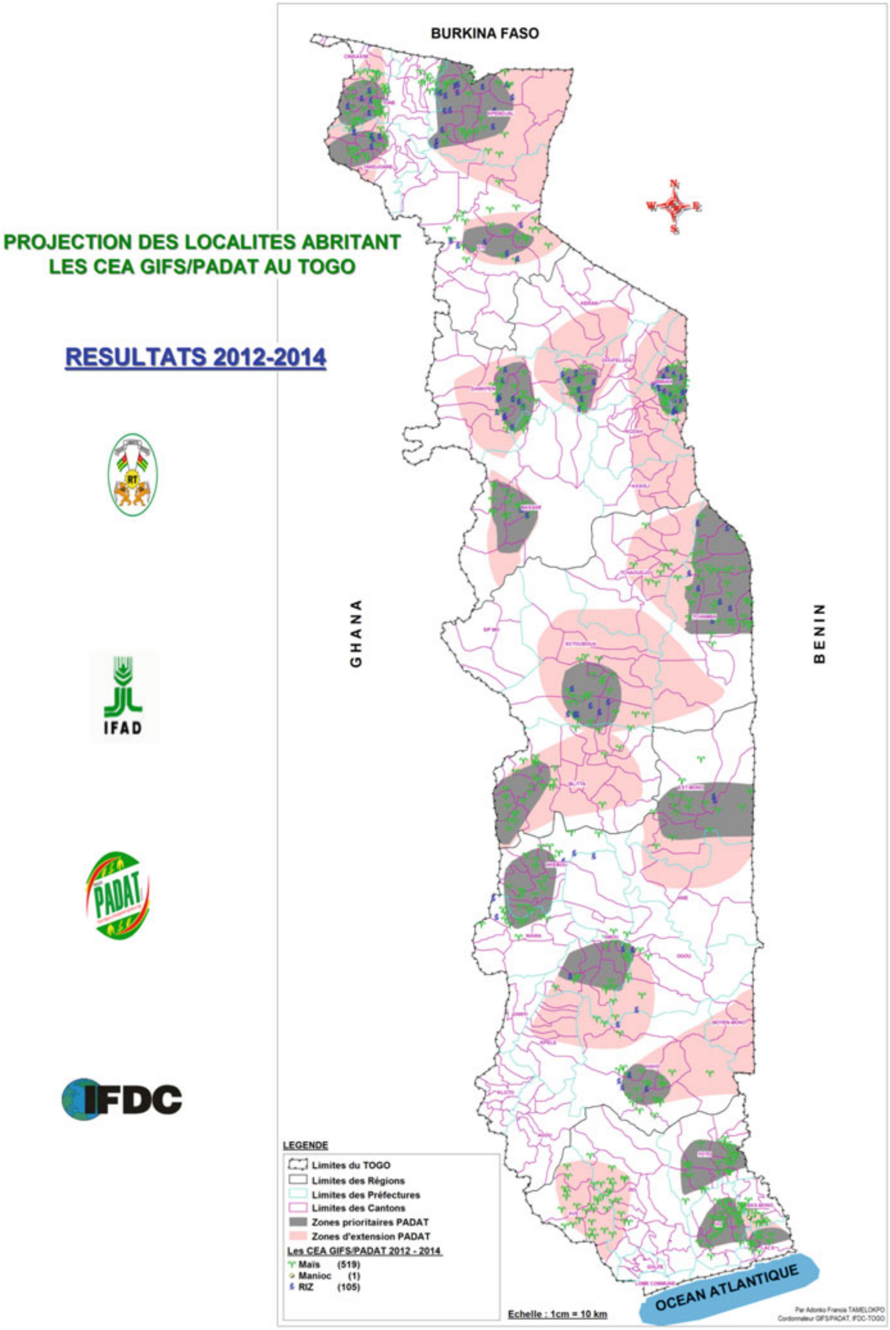
In the *Central region of Kara and Savanes* – associations maize-sorghum, maize – cowpea, maize-groundnut, maize-rice and maize and rice in pure cropping (Map 10.1).

10.8.1.1 Farmer Field School for ISFM Learning and Implementation

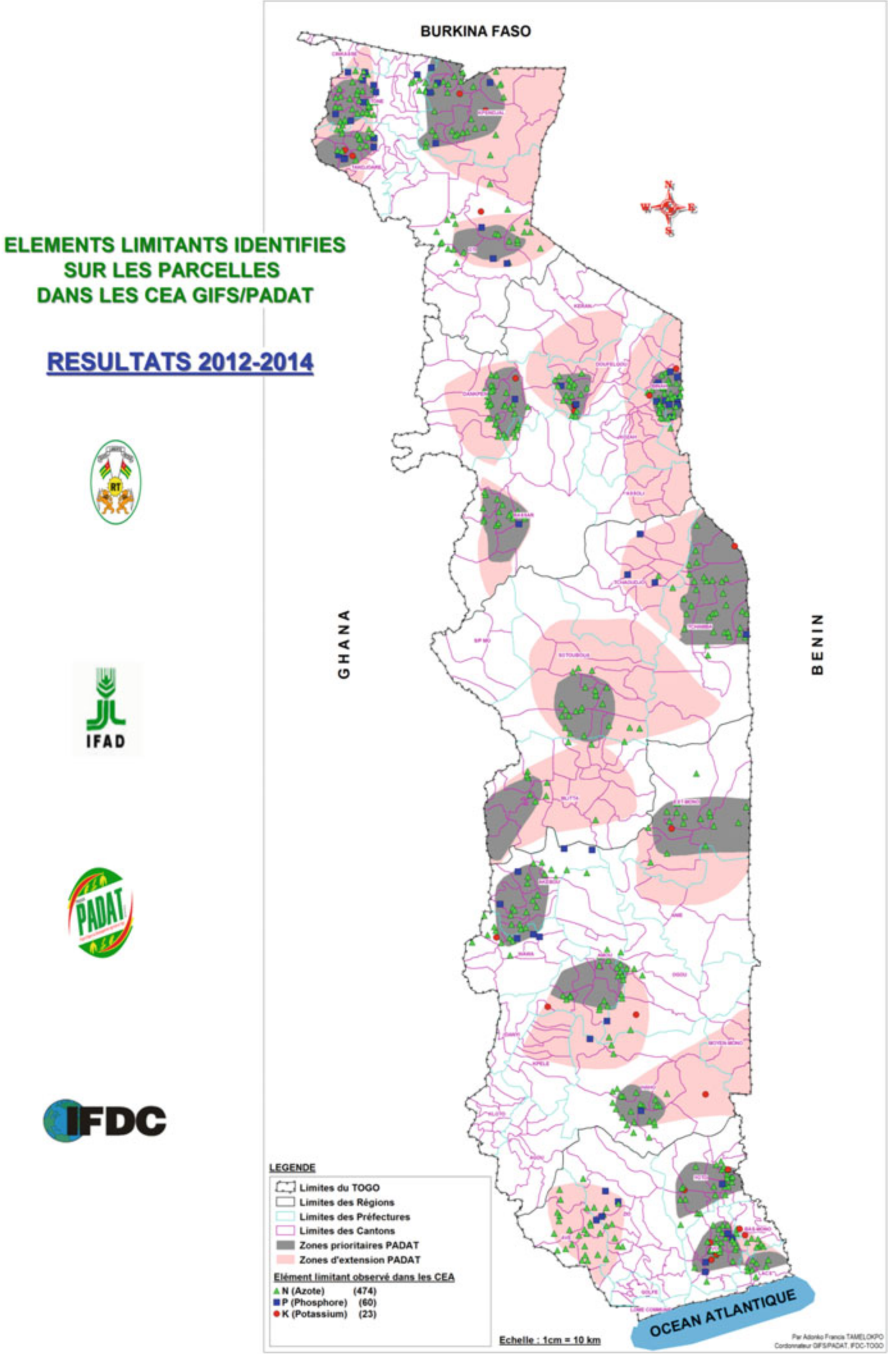
Following the rapid PD carried out in 592 villages, 628 ISFM-FFS were installed, including 131 in the Maritime Region, 114 in the Plateaux Region, 114 in the Central Region, 128 in the Kara Region and 141 in the Savanes region. Of the 628 ISFM-FFS installed, 557 were managed under the participatory nutrient omission trials which allowed to identify the limiting nutrients to crop yields (Map 10.2).

10.8.2 Results of Nutrient Omission Trials for the 2011–2012 Agricultural Season in Togo

Analysis of the results shows that the most limiting nutrient is nitrogen, followed by phosphorus. As for potassium, it limits to a lesser extent the yields of maize and rice



Map 10.1 Projection of locations with farmer field schools



Map 10.2 Limiting nutrients identified in farmer field schools

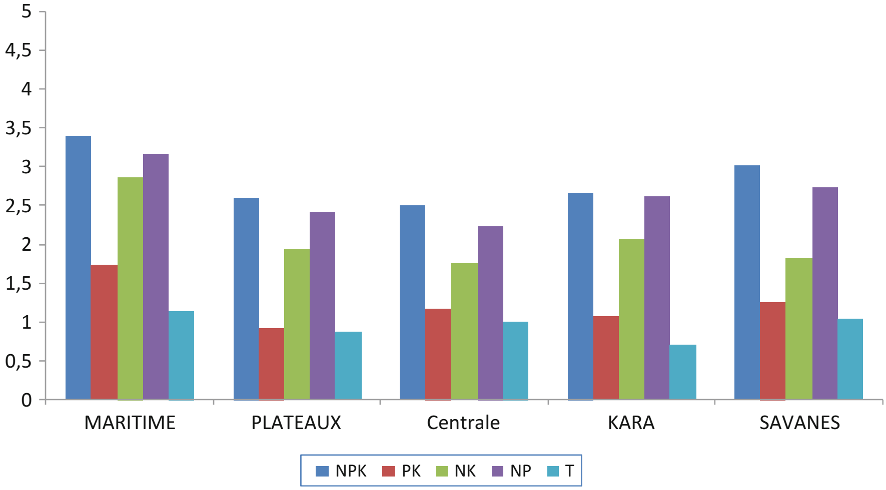


Fig. 10.4 Grain yields per region 2011–2012

Table 10.5 Average grain yields for maize (t/ha)

Treatments	Grain weight
NPK PK	2,8379 A
NK NP	1,2217 C
CONTROL	2,1644 B
	2,6369 A
	0,9525 C

Averages followed by different letters are statistically different at the 5% treshold (test of Student-Newman-Keuls)

in all regions. Also, it was found that the effects of nutrients differ from one region to the other, but the trends remain the same with nitrogen having a more limiting effect on yields. In fact, the different formulations did not produce the same effects in all regions (Fig. 10.4). It is therefore very important to take into account the specific realities of each agro-ecological zone in the formulation of fertilizers.

10.8.2.1 Yields in Grain Maize

The best yields were achieved on the plots that received NPK. Yields on these plots are not statistically different from those on the plots that received PR only (Table 10.5). This indicates that these soils are fairly well supplied with potassium (K).

It appears that the limiting nutrient to soil fertility in Togo remains nitrogen (N). However, it should be noted that soil needs vary from one agro-ecological zone to another. This should be taken into account in the formulation of fertilizers. It is necessary to expand the participatory nutrient omission trials to other locations for a wide dissemination of results achieved, and facilitate ownership by extension services.

10.8.2.2 Geographical Projection of Yields

The 628 FFSs were geo-referenced and the results projected on the PADAT area maps. Maize and rice yields achieved are analyzed using the MAPINFO model. The results confirmed that FFS' soils have lower contents in nitrogen (Table 10.6).

Projection of yields obtained on the control plots without fertilizers revealed that on a sample of cases in Togo, poor and very poor soils account for 496 cases, or 89% (Map 10.3). Projection of the results of nutrient omission trials showed that out of 557 cases, nitrogen limits the yields of maize and rice in 85% of cases, phosphorus in 11% and potassium in only 4% of cases.

Soil P deficiencies are randomly distributed in the country but appear to be more concentrated in the regions of Kara and Savanes than in the South (Map 10.2) (Bationo & Mukwunye 1991b). The projection of the different options gave interesting results (Table 10.7).

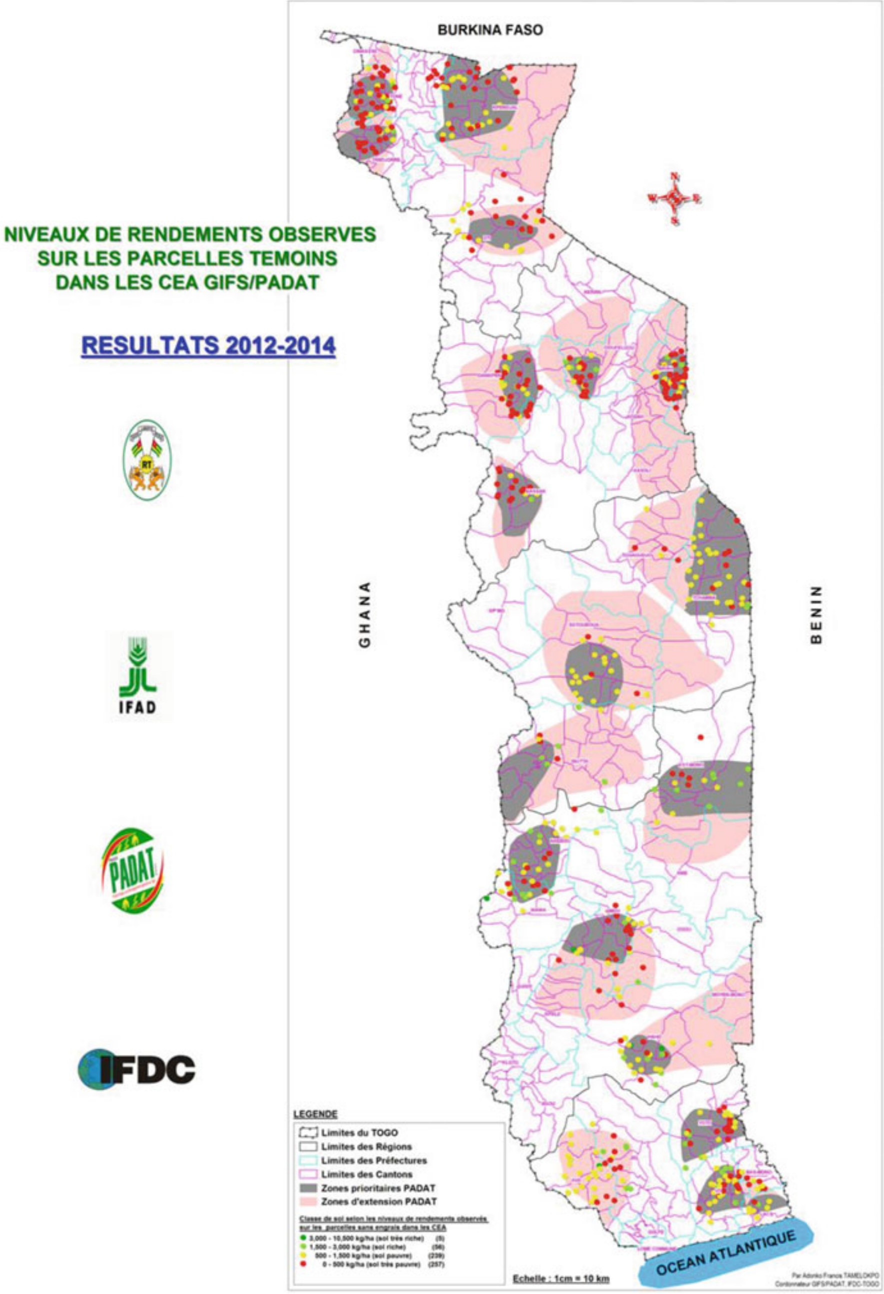
Increasing the amount of nitrogen in fertilizer formulas enables to improve yields. On a sample of 557 FFSs it was found that with the same fertilizer rate (300 kg/ha), the supply of 150 kg of NPK 15-15-15 + 150 kg of urea allowed in 437 FFSs or 78% of the cases, to achieve yields higher than those obtained with the supply of 200 kg of NPK 15-15-15 + 100 kg of urea. The reverse trend and equivalent cases are only observed in 120 FFSs (22% of cases) (Maps 10.4, 10.5, 10.6, 10.7 and 10.8).

The capacity of the selected options to improve yields in the FFSs is expressed by the number of FFSs having produced yields in a given yield stratum relative to the size of the FFS sample considered (in%) (Table 10.7).

Table 10.6 Farmers' perception of current soil fertility status

Soils	Very poor pauvres	Poor	Rich	Very rich
Yield (kg/ha)	500	1500	3000	5000
Maize value (FCFA)	80,000	240,000	480,000	800,000
Farm-gate prices (FCFA)	86,997	95,191	107,481	123,869
RVC	0,9	2,5	4,5	6,5

If the soil produces less than 0.5 t/ha – it is very poor
If the soil produces between 0.5 and 1.5 t/ha – it is poor
If the soil produces between 1.5 and 3 t/ha – it is rich
If the soil produces more than 3 t/ha – it is very rich
Source: Farming environment in Togo



Map 10.3 Yields levels on controls without fertilizers

Table 10.7 Capacity of options to improve yields in FFSs (%)

Options	Sample size (FFS)	Yields stratum			
		<500 kg. ha^{1}	500–1500 kg. ha^{1}	1500–3000 kg. ha^{1}	>3000 kg. ha^{1}
Control	557	46,1	42,9	10,1	0,9
PP	557	9,2	38,1	43,4	9,3
ISFM	557	2,0	11,5	35,4	51,1
4NPK + 2 U	557	2,3	21,0	44,2	32,5
3NPK + 3 U	557	2,0	16,9	36,8	44,3

NB: U – Urea

10.9 Conclusion

The results show the importance of nutrient omission trials for participatory soil fertility diagnosis. It was shown that the major limiting nutrient to soil fertility in Togo remains nitrogen (N). The same result was obtained in 2006 and 2007 in Benin at Djougou. However, it should be noted that soil needs are highly variable from one agro-ecological zone to another. Therefore, this must be taken into account in the formulation of fertilizers. In the short term and given the current fertilizer and options available in the country, increasing the amount of nitrogen in fertilizer formulas enables to achieve higher yields. On a sample of 557 farmer field schools (FFS) it was found that with the use of the same fertilizer rate (300 kg/ha), the supply of 150 kg of NPK 15–15-15 + 150 kg of urea resulted in 78% of yields exceeding those achieved with the supply of 200 kg of NPK 15-15-15 + 100 kg of urea.

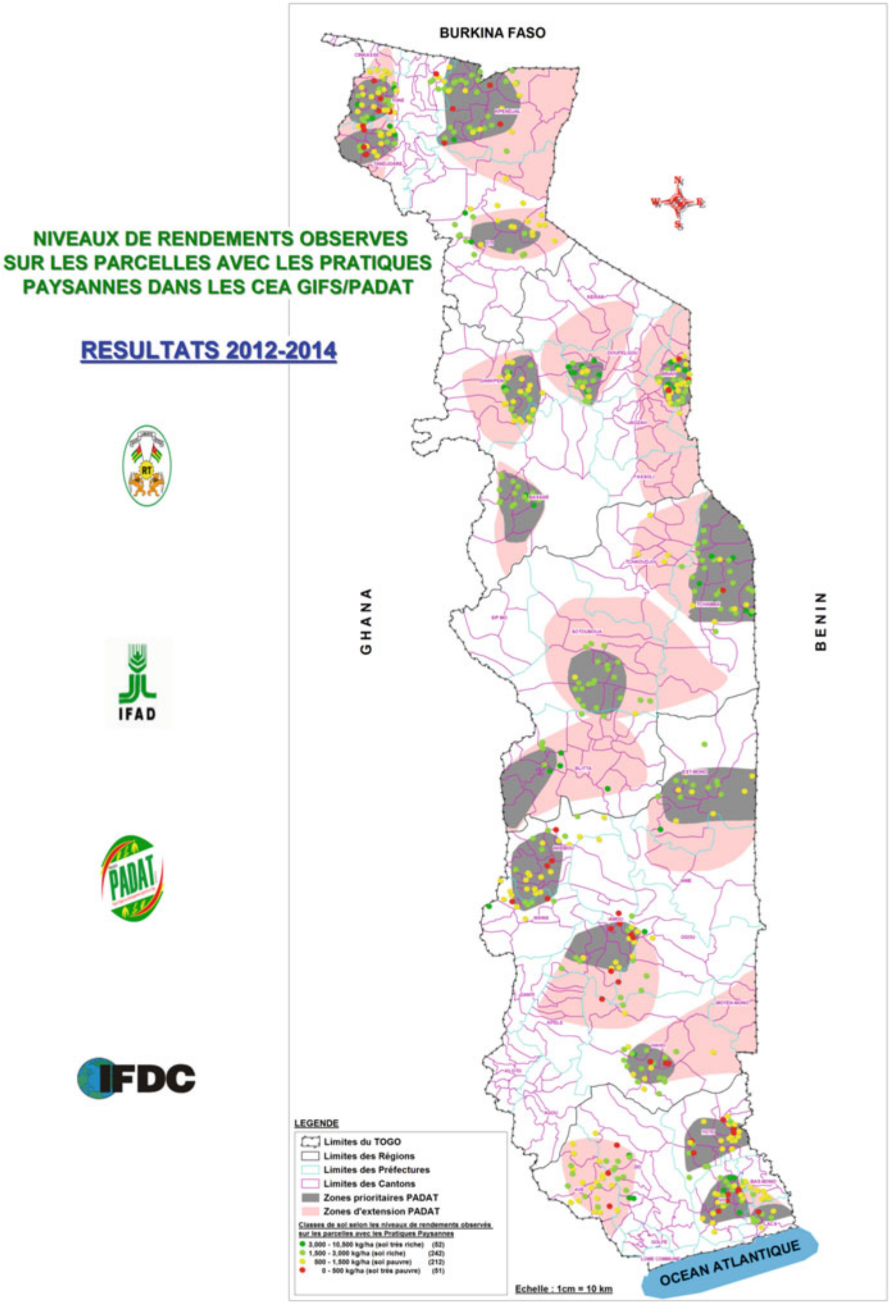
- Diammonium phosphate combined with urea may be considered, as most soils have high K contents;
- Straight fertilizers are needed for specific replenishments based on fertilizer recommendations.

10.10 Perspectives

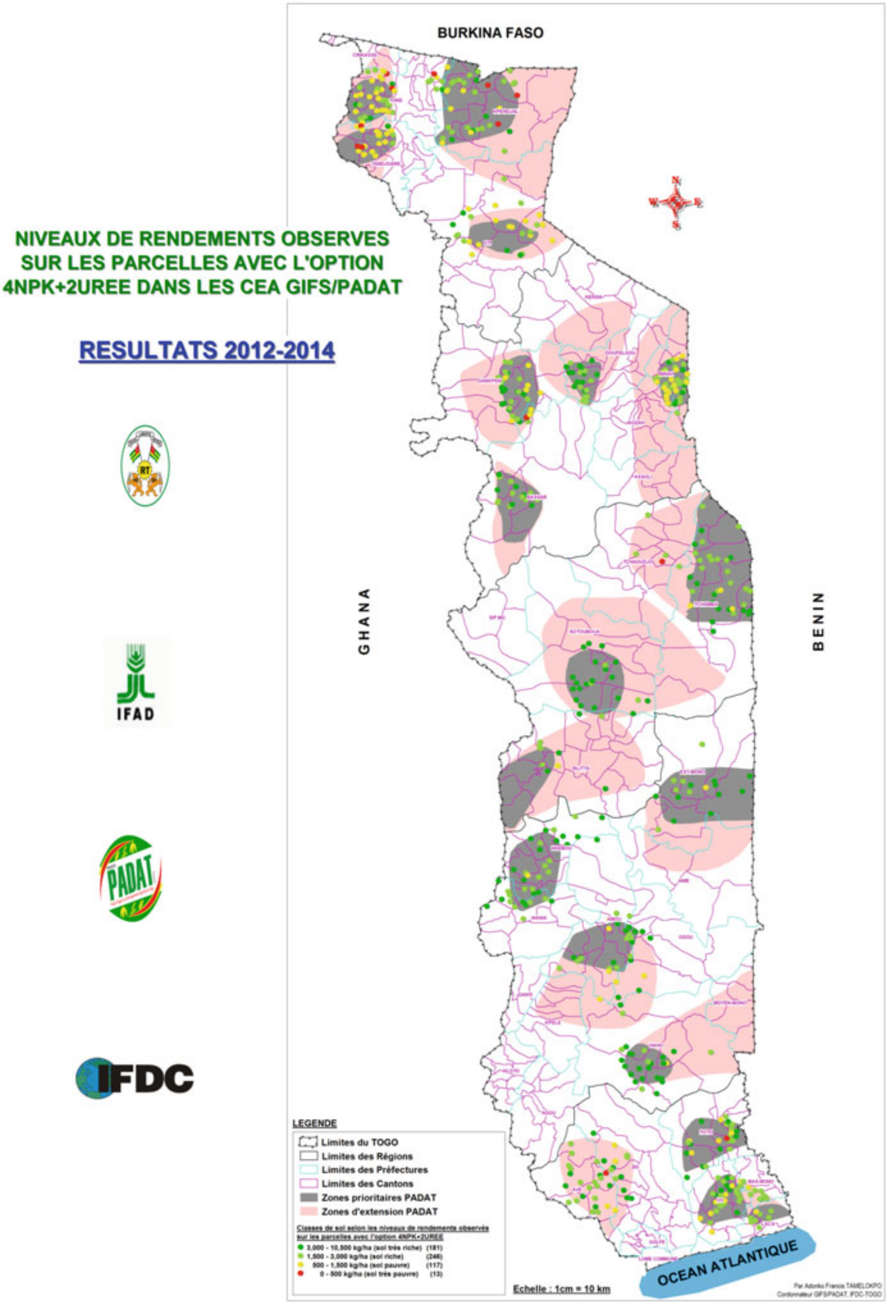
Encouraging results have been achieved towards increasing agricultural productivity.

To support these results and facilitate widespread adoption of ISFM options, the following actions should be considered through a pilot project aiming at:

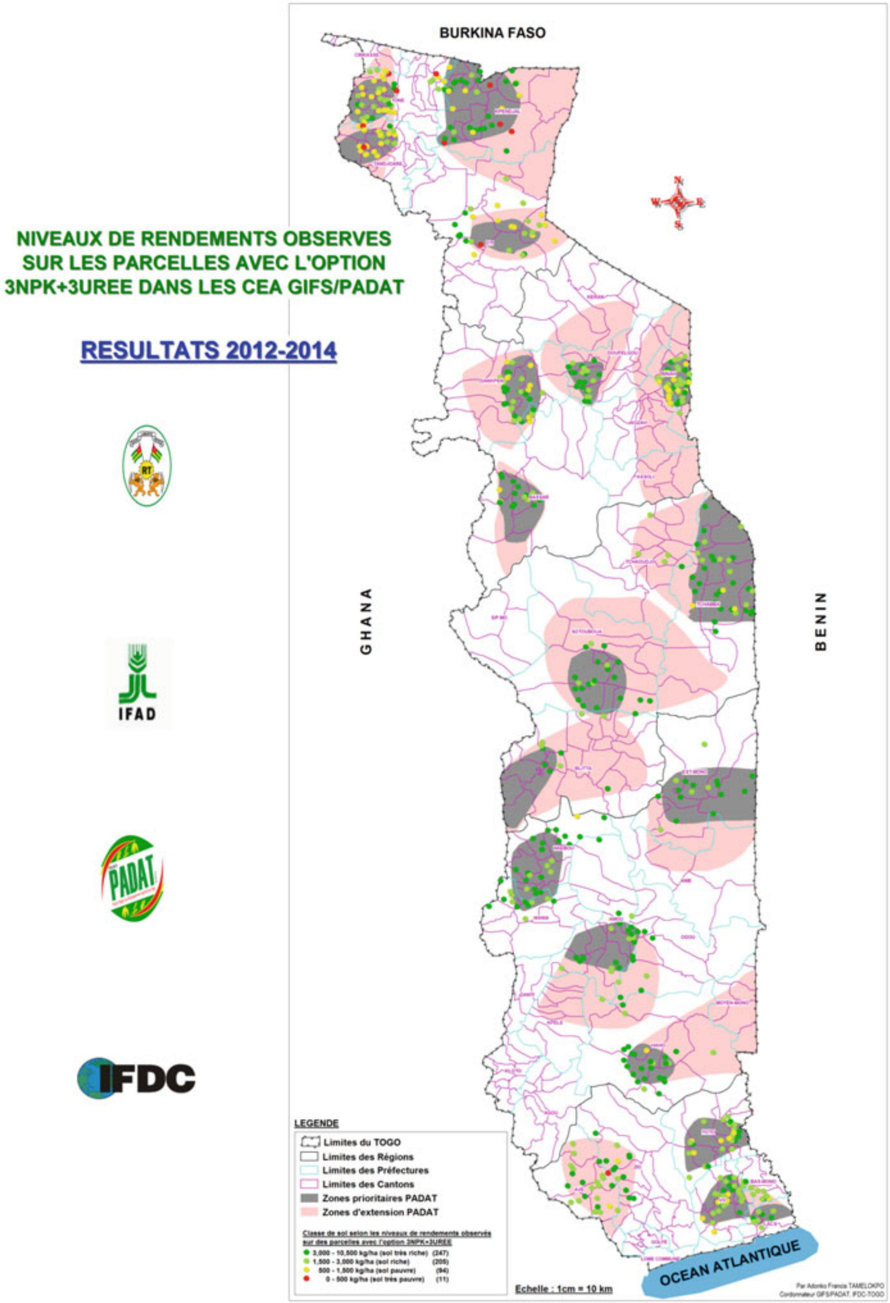
- Exploiting the overall results achieved on soil fertility; carrying out rapid analyzes of soil samples in representative locations to use QUEFTS (Struif Bontkess et al. 2003) for in-depth analyses and extrapolation of recommendations. This model coupled with the MAP Info can improve the reliability of these extrapolations.



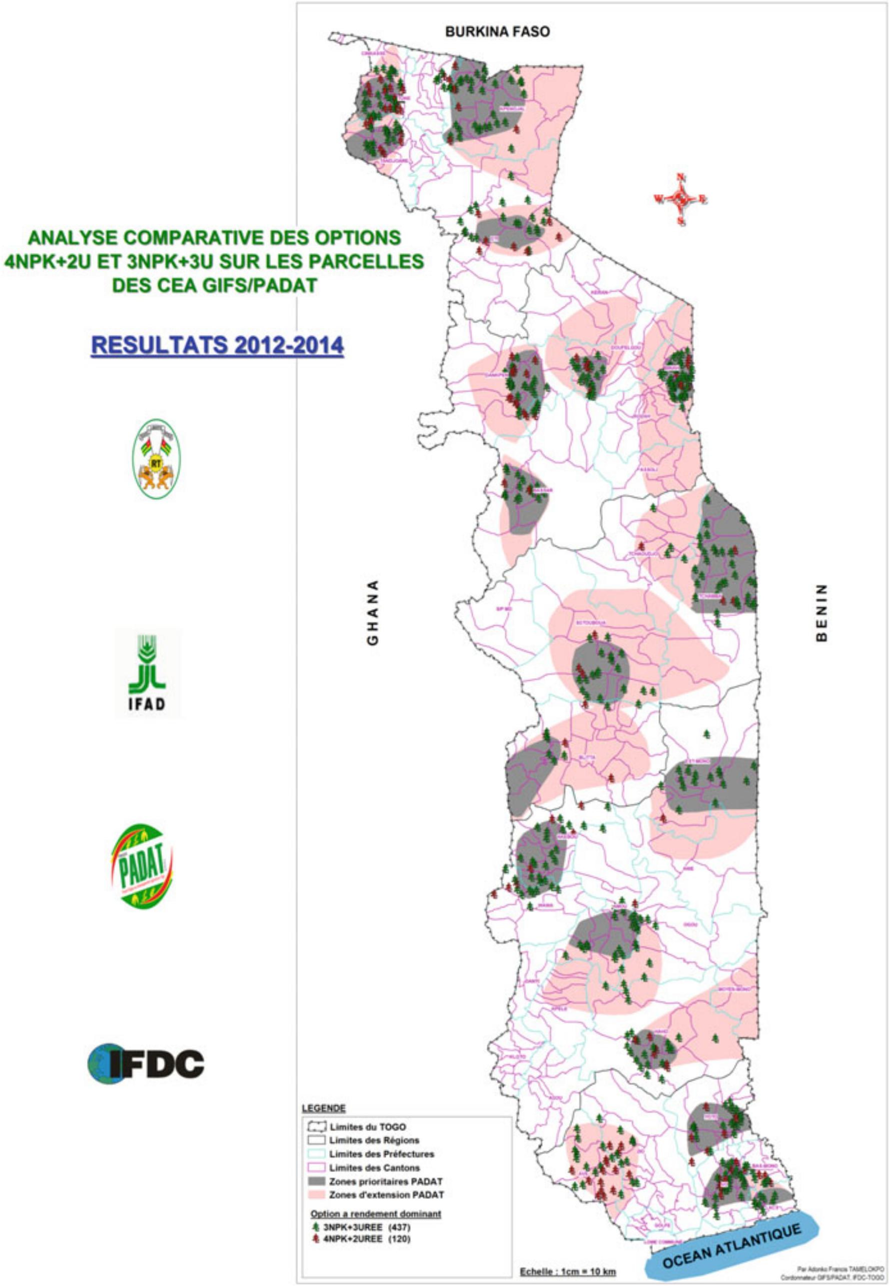
Map 10.4 Yield levels under farmer practice



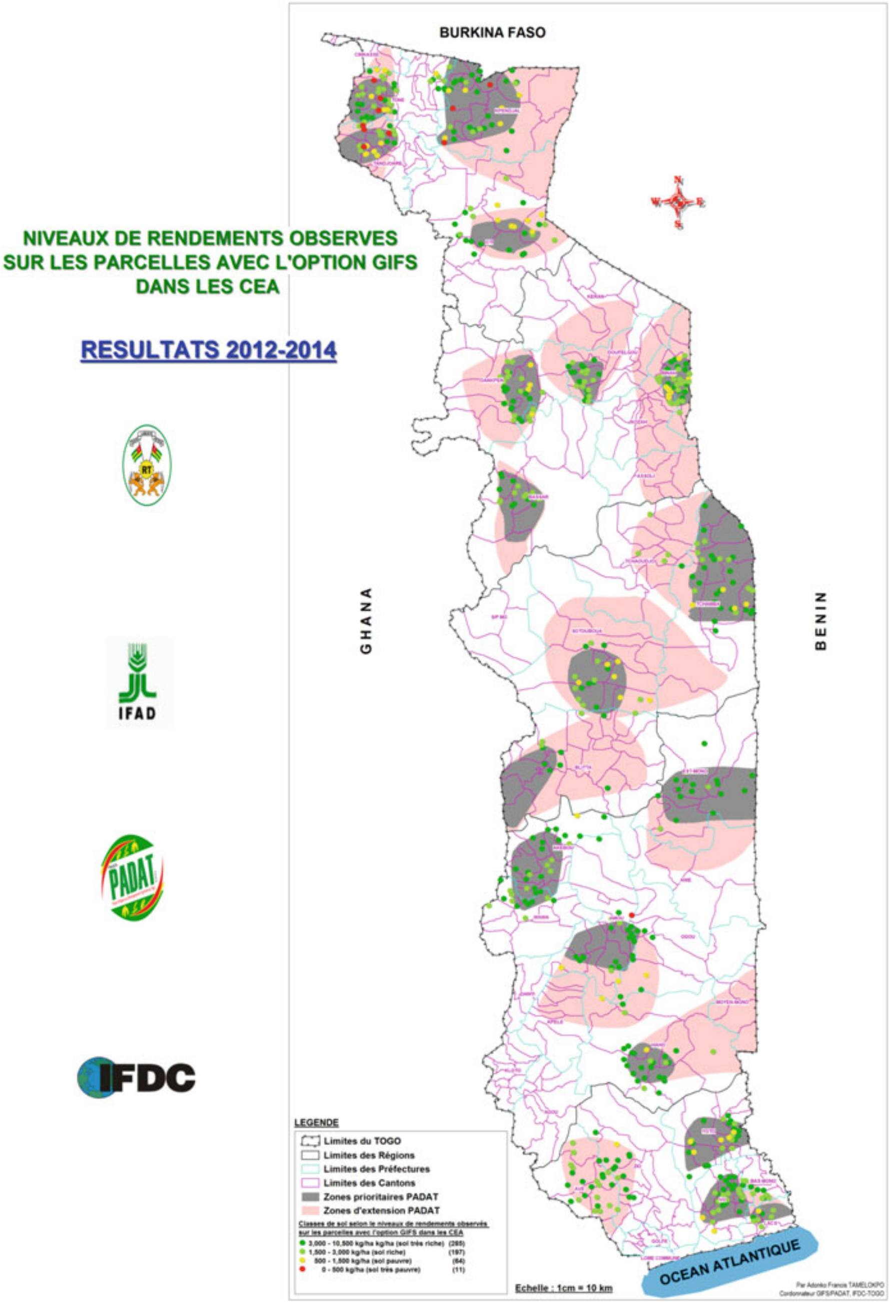
Map 10.5 Yield levels with 4NPK + 2 Urea



Map 10.6 Yield levels with 3NPK + 3 Urea



Map 10.7 Comparative analysis of options 3NPK + 3 Urea and 4NPK + 2 Urea



Map 10.8 Yield levels under the ISFM option

- Correlation and soil analysis taking into account farmers' endogenous knowledge with a view to extending ISFM activities to areas not covered in Togo and in the sub-region,
- Developing mechanisms to facilitate access to inputs in Togo and the West African sub-region 'taking into account the PSFD results.
- Supporting actions through the creation of a sub-regional network to ensure continuous support to technical partners, extension workers and endogenous trainers and the use of participatory nutrient omission trials as a tool to facilitate decision-making in fertilizer recommendations.
- Strengthening the capacities of farmers and extension workers in the facilitation of participatory soil fertility diagnosis for rapid adaptations of fertilizers recommendations if needed.

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Chapter 11
Taking Stock of Fertilization in the Cultivation of Maize, Millet/Sorghum, Cowpea, Rice and Cotton in Mali

M. Koné, H. Konaré, M. Dicko, and F. Sissoko

Abstract In Mali, contrasted agro-ecological zoning has led to a broad diversification of cultivated crops. Due to soils low inherent fertility technical recommendations for organic--mineral fertilization are required to improve agricultural production and productivity.

The old standard fertilizer recommendations regarding major crops have met with low levels of adoption by farmers due to the high cost of mineral fertilizers. Inadequate fertilization practices and widespread agricultural extensification have caused a sharp physical, chemical and biological degradation of cultivated soils.

Today, new fertilizer recommendations that are better suited to soil evolution, cropping practices and crop needs will enable to boost agricultural production despite adverse climate changes. Ultimately, sustained government agricultural subsidy and the availability of fertilizer blending plants would be powerful levers for widespread adoption of these recommendations towards a prosperous agriculture.

Keywords Recommendations • Soil fertility • Fertilization • Fertilizers • Mali

Contents

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11.1 Introduction

Mali is a vast Sahelian country of about 1,200,000 km^2 with a population estimated at 14.5 million inhabitants, of which 80% have an agro-pastoral vocation. Hence, this country offers great agro-sylvo-pastoral potential. From the colonial era to date, Mali's agricultural policy has been based on the intensification of agriculture to feed its rapidly growing population and foster economic development. However, the Malian economy is mainly based on the primary sector dominated by extensive agriculture and transhumant stockbreeding.

11.2 Agricultural Zoning and Cropping Systems

Mali's agricultural environment exhibits a wide disparity in agricultural production systems, level of intensification, use of manure and mineral fertilizers, population density and agricultural development activities given the agro-ecological constraints and potential.

According to Kieft et al. (1994), from the agro-ecological point of view, the following main agricultural production zones are found in Mali:

- ***The south-Sudanian zone*** covering 6% of the national territory, with an annual rainfall ranging from 1300 to 1500 mm/year. It is the agricultural zone by excellence which produces all food crops and cash crops such as cotton and groundnut. Forest resources are abundant. Livestock production development is related to cotton growing intensification as it represents a means of reinvesting cotton incomes for farmers.
- ***The north-Sudanian zone*** covering 20% of the national territory, with an annual rainfall ranging from 700 to 1300 mm/year. Cereal crops are predominant such as millet and sorghum, followed by cotton, groundnut, food legumes, irrigated rice and flooded rice. Livestock production and fisheries are undergoing great development.
- ***In the south-Sudanian zone*** as well as the north-Sudanian-zone, cotton consumes 75% of mineral fertilizers, not to mention maize, millet, sorghum and groundnut which benefit from the residual effects of cotton fertilizers within the crop rotation system.
- ***The Sahelian zone*** covering 20% of the national territory (excluding the Niger Delta) with an annual rainfall ranging from 200 to 700 mm/year. The main cereal crops are millet, sorghum and flooded rice. Fisheries resources which were previously important are in sharp decline. In this area, mineral fertilizer use is very limited at about 5%.
- ***The south-Saharan zone*** covering 50% of the national territory with irregular and accidental annual rainfall less than 200 mm/year. Livestock production is the dominant activity. The main cereal crops are millet and sorghum as flood recession crop in wetlands, almost without use of mineral fertilizers.

- ***The Inner Niger Delta*** covering 6% of the territory. Livestock production is the dominant activity. However irrigated rice (Office du Niger), flooded rice and sugar cane are widely cultivated. In this area, the use of mineral fertilizers is limited at about 20% annually.

Based on this diversified agro-climatic zoning, the Government has set itself the priority goal of making Mali an agricultural power through the Law of Agricultural Orientation (LOA 2006). Mechanization and support to the efficient use of agricultural inputs, particularly fertilizers and certified seeds through subsidies, are the tools for improving agricultural production and productivity and the best way for reaching food security and sovereignty. Overall, agricultural production in Mali revolves around three main cropping systems: the rice area of the Office du Niger, the cotton area and the dry cereal farming area.

11.3 Soil Fertility and Crop Fertilization

Soil degradation undermines the sustainability of the main agricultural and livestock production systems in Mali due to climate variability, soil erosion, low inherent soil fertility and, above all, extensive and unsustainable use of natural resources (Koné and Doumbia 1997). Each cropping system encounters technical difficulties for its intensification and sustainability in Mali. Most cultivated soils are leached ferratilic and ferruginous tropical soils.

Regarding crop fertilization two types of fertilizers are mainly used, namely mineral fertilizers either imported or produced locally, and organic fertilizers with a progressive integration of agriculture and livestock production in farmers' fields.

11.3.1 Mineral Chemical Fertilizers

Mali is one of the largest fertilizer consumers in West Africa, thanks to the leading role played by cotton and irrigated rice. To increase soil fertility level and improve soil productivity, farmers are increasingly using mineral and organic fertilizers. Consumption of mineral fertilizers rose from 84,800 tons in 1994 to 175,000 tons in 2009 and 250,000 tons in 2011, despite fertilizer prices urges in 2007 and 2008. The use of chemical fertilizers in Mali reached 300,000 tons in 2012.

The types of chemical fertilizers, their formulas and their application rates are based on the results of agronomic research and are disseminated to producers by extension offices (Table 11.1).

Table 11.1 Summary of the various chemical fertilizers used in Mali

Fertilizer type	Crop	Composition %					Rates Kg/ha
		N	P_2O_5	K_2O	S	B	
Cotton complex	Cotton	14	18	18	6	1	150 à 200
		14	22	12	7	1	
		22	13	12	7	1	
Ceralcomplex	Maize, millet, sorghum	15	15	15	–	–	100
		17	17	17	4	–	
		16	16	16			
Urea	Cotton cereals	46	–	–	–	–	50
							100 à 150
Sprinter	Cotton	24	6	12	–	–	100
Diammonium phosphate	Rice,	18	46	–	–	–	100
	Sugar cane						200 à 300
Super simple	Groundnut, cowpea	–	20	–	–	–	75
Triple super		–	46	–	–	–	75
NPK		6	20	10			50
Potassium chloride	Sugar cane	–	–	60	–	–	150 à 200
NPKS	Cereals	16	16	16	–	–	100
(Nyéléni, Sugubè-	Rice	16	26	12			150 à 200
Sugubè) Actyva	Maize, wheat	23	10	5			250
Partner	Potato, vegetable farming	12	11	18	8		400 à 800
	Sweeet peas						100
Tilemsi phosphate rock	All crops	–	29	–	–	–	100300

11.3.2 Organic Fertilizers

Manure is a source of nutrients (mineral and organic) that can improve soil fertility and crop nutrition and yields. In addition, manure improves the physico-chemical and biological properties of cultivated soils. There are several types of manure used by farmers, but overall the amounts produced are insufficient to cover the needs (Table 11.2).

Overall these organic materials are of very low grade, especially low in phosphorus and with a large variable chemical composition.

11.4 Main Fertilizer Recommendations for Crops in Mali

Most soils under cultivation are tropical ferruginous soils (Traoré 1972) with severe deficiencies in phosphorus, nitrogen and sulphur, and low secondary deficiency in potassium. This requires the use of nitrogen and phosphate fertilizers on dry cereals. Today, highly deficient mineral balances and acidification have led to a widening

Table 11.2 Summary of the different organic fertilizers used in Mali

Fertilizer type	Crop	Composition %					Rates T/ha
		N	P_2O_5	K_2O	Ca	Mg	
Sabugnuma[a]	All crops	0,72	8,36	0,56	3,0	0,6	1 à 3
Toguna, elephant vert	All crops	3.0	5.0	3.0	5.0	3.0	1 à 3
Orgafert	Cotton, cereals	1,5	2.27	0,6	9.5	1.9	1 à 3
Compost	Cotton, cereals	0,9	0,3	1,5			5 à 15
Park land (withstraw)	Cotton, cereals	1,1	0,4	1,9			5 à 15
Park land (withoutstraw)	Cotton, cereals	1,2	0,5	1,8			5 à 15
Householdwaste	Cotton, cereals	0,5	0,3	0,8			5 à 15

[a] *Sabugnuma was enriched with phosphorus by the addition of TPR (IER/Labo SEP)*

gap in potassium and exchangeable cation balances, hence the interest of new recommendations on major cereals. Cotton fertilization was based on DAP and urea, the addition of potassium, sulphur and boron was introduced with the emergence of the African cotton fertilizer around 1980.

11.4.1 Maize Fertilizers

The addition of sulfur and zinc to the NP basal dressing improves yields (Table 11.3).

11.4.2 Millet/Sorghum Fertilizers

The addition of potash and sulfur to the NP basal dressing improves productivity (Table 11.4)

11.4.3 Cowpea Fertilizers

Crop associations and crop rotations practiced by farmers are more important than the specific mineral fertilization of cowpea (Table 11.5).

11.4.4 Rice Fertilizers

The addition of potash, sulfur and zinc to the NP basal dressing improves productivity (Table 11.6).

Table 11.3 Main fertilizer recommendations for maize in Mali

Fertilization	Rates/ha and fertilizer types	Composition $N-P_2O_5-K_2O$	Applications
Mineral	100 kg of diammonium phosphate	41-46-0	Tillage, stem elongation
	+ 50 kg of urea		
	100 kg of cotton complex	37-22-12	Tillage, stem elongation
	+ 50 kg of urea		
	100 kg of diammonium phosphate	41-46-25	Tillage, stem elongation
	+ 60 kg de sulfate de potassium		
	+ 50 kg of urea		
	200 kg de complexe coton	97-44-24	Tillage, stem elongation
	+ 150 kg of urea (split application)		
	200 kg of diammonium phosphate	105-92-60	Tillage, stem elongation, hilling
	+ 120 kg of potassium sulfate		
	+ 150 kg of urea (split)		
	100 kg of cereal complex	84-15-15	Tillage, stem elongation, hilling
	+ 150 kg of urea (split)		
	200 kg of cereal complex	122-15-15	Tillage, stem elongation, hilling
	+200 kg of urea (split)		
	100 kg maize fertilizer (23-13-13)	92-13-13	Tillage, stem elongation, hilling
	+ 150 kg of urea (split)		
Organo-mineral	2 T of droppings (2.2-1.9-1.4)	128-53-44	Tillage, stem elongation, hilling
	+ 100 kg of cereal complex		
	+ 150 kg of urea (split)		
	4 T of droppings (2.2-1.9-1.4)	130-84-66	Tillage, stem elongation, hilling
	+ 50 kg of cereal complex		
	+ 75 kg of urea (split)		

Table 11.4 Main fertilizer recommendations for millet/sorghum in Mali

Fertilization	Rates/ha and fertilizer types	Composition $N-P_2O_5-K_2O$	Applications
Mineral	100 kg of diammonium phosphate	41-46-0	Tillage, stem elongation
	+ 50 kg of urea		
	100 kg of cereal complex	38-15-15	Tillage, stem elongation
	+ 50 kg of urea		
	5 kg of cereal complex (15-15-15 ou 16-16-16)	1-1-1	Sowing
	50 kg of cereal complex (15-15-15 ou 16-16-16)	8-8-8	Sowing
	35 kg of cerealcomplex (15-15-15)	5-5-5	Sowing
Organo-mineral	4 T of organic fertilizer		Tillage, stem elongation
	+ 50 kg of diammoniumphosphate		

Table 11.5 Main fertilizer recommendations for cowpea in Mali

Fertilization	Rates/ha and fertilizer types	Composition N-P_2O_5-K_2O	Applications
Mineral	50 kg of simple super phosphate	0-11-0	Emergence
	50 kg of phosphate rock	0-14-0	Labour

Table 11.6 Main fertilizer recommendations for rice in Mali

Fertilization	Rates/ha and fertilizer types	Composition N-P_2O_5-K_2O	Applications
Mineral			
Lowlandrice	200 kg of complex (14-22-12)	74-44-24	Sowing, tillering, heading
	+ 100 kg of urea (split)		
Irrigatedrice	100 kg DAP	87-46-0	Sowing, tillering, heading
	+ 150 kg of urea (split)		
	100 kg of Gnéléni	85-26-12	Sowing, tillering, heading
	+ 150 kg of urea (split)		
Organo-mineral			
Lowlandrice	5 T organic fertilizer		Sowing, tillering, heading
	+ 100 kg of urea (split)		
Irrigatedrice	5 T of organic fertilizer		Sowing, tillering, heading
	+ 150 kg of urea (split)		

11.4.5 Cotton Fertilizers

The addition of magnesium, sulfur and boron to the NP basal dressing improves productivity (Table 11.7).

11.5 Fertilizer Adoption and Suggestions for Improved Crop Fertilization

Fertilizers play a major role in increasing agricultural production in the Sahel. A gradual improvement of agricultural policies in developing countries has promoted fertilizer use, distribution and price through international tenders and a significant development of the local production of fertilizer blends. Increasing crop yields on soils with low inherent fertility requires more extensive and more efficient use of chemical fertilizers as well as organic fertilizers.

The fertilizer sector in Mali involves local fertilizer production, international or bilateral aids and especially imports from Africa, Europe and Asia. The volume of fertilizer imports reached 50,000 tons in 1980, today it exceeds 600,000 tons per year for cotton, maize, rice and sugar cane.

Table 11.7 Main fertilizer recommendations for cotton in Mali

Fertilization	Rates/ha and fertilizer types	Composition N-P_2O_5-K_2O	Applications
Mineral	200 kg of cotton complex (14-22-12-7-1)	51-44-24	Emergence, hilling
	+ 50 kg of urea		
	150 kg of cotton complex (14-22-12-7-1)	44-33-18	Emergence, hilling
	+ 50 kg of urea		
	150 kg of cotton complex (14-18-18-6-1)	44-27-27	Emergence, hilling
	+ 50 kg of urea		
	150 kg of cotton complex (22-13-12-5-0.7)	56-20-18	Emergence, hilling
	+ 50 kg of urea		
	150 kg of cotton complex (14-22-12-7-1-5MgO)	44-33-18	Emergence, hilling
	+ 50 kg of urea		
	150 kg of cotton complex (14-23-14-4-1-5 CaO)	44-25-21	Emergence, hilling
	+ 50 kg of urea		
	150 kg of TPR	50-42-27	Emergence, hilling
	+ 150 kg of cotton complex (18-9-18-7-1)		
	+ 50 kg of urea		
Organo-mineral	5 T of organic fertilizers		Tillage, emergence, hilling
	+ 150 kg of cotton complex (18-9-18-7-1)		
	+ 50 kg of urea		
	3 T of organic fertilizers		Tillage, emergence, hilling
	+ 150 kg of cotton complex (18-9-18-7-1)		
	+ 50 kg of urea		

Thanks to the support of IFDC and CNFA, the fertilizer distribution network is now properly organized. Today, mineral fertilizers are available in towns, villages and even in remote hamlets closer to farmers. A national directory of input distributors in Mali has just been published by CNFA with over 2000 references of agro-dealers covering the whole country (CNFA 2010).

For the agricultural season 2014/2015 in Mali, according to the final results of the Conjonctural Agricultural Survey (CAS) cereal production was estimated at 6,980,733 tons. Compared to the results of the 2013–2014 season, which were estimated at 5,736,093 tons, there was an increase of 22%. This represented 81% of the season objective of 8,674,462 tons. Cereal production figures for the 2014–2015 season are given in Table 1 in the Annex and in Fig. 11.1. They are broken down as follows:

- 2,166,830 tons of rice (31%)
- 1,744,026 tons of maize (25%)
- 1,715,044 tons of millet (24,6%)
- 1,271,880 tons of sorghum (18,2%)
- 37,284 tons of fonio (0,5%)
- 45,668 tons of wheat/barley (0,7%) (Fig. 11.2).

Fig. 11.1 Mali agricultural zoning

Fig. 11.2 Results of cereal production distribution for major crops

According to FAO consumption standards of (214 kg/person/year), the overall cereal production for the 2015/2016 season showed a cereal surplus, estimated at 1,831,330 tons. However, this surplus is very theoretical as it does not take into account possible cereal outflows, quantities intended for processing and for livestock and poultry feed. It also does not take into account the quantities of cereals produced but not accessible because of the remoteness of some production areas.

The evolution of cereal production in the country from the 2006/2007 crop year to the 2013/2014 crop year is shown in Fig. 11.3.

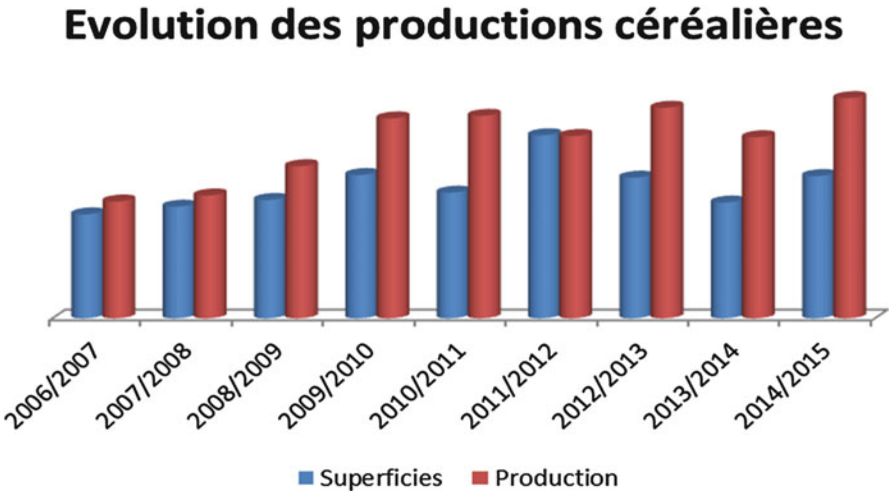

Fig. 11.3 Evolution of cereal production from 2006/2007 to 2013/2014

This graph shows that:

- Cereal production increased from 3,693,240 tons in the 2006–2007 crop year to 6,980,733 tons in the 2014–2015 crop year, an annual average increase of approximately 11%.
- The average annual growth rate of the lands under cultivation is of 5%.

It may be deduced that significant efforts have been made to ensure the intensification of agricultural production since the 2008–2009 crop year by extension offices.

Seed cotton production in the 2014–2015 crop year is estimated at 548,723 tons. It was 440,027 tons in 2013–2014, an increase of 24.7%. This production could have been better if agro-climatic conditions had been favorable (distribution of rainfall over time and space, quantities and frequency of recorded rainfall, control of the artificial rain program).

In the past, high cost of mineral fertilizers and poor organization of agricultural markets led to fertilizer under-dosing and non-application by farmers of standard recommendations developed for major crops. Even on industrial crops (cotton, tobacco and groundnut) with a guaranteed market, producers opted for economic fertilizer rates that minimize their financial risks rather than maximizing crop yields and maintaining soil fertility. Extreme deficient mineral balances have further contributed to worsening the physicochemical and biological depletion of cultivated soils (Piéri 1989; Van der Pol 1991; Kieft et al. 1994; Koné et al. 1987) with a sharp reduction of land fallow (previously practiced to ensure soil fertility restoration). Saturation of the arable space due to population explosion (Brethé et al. 1991) led farmers to occupy marginal areas and rangelands accelerating soil erosion and land degradation.

Today, climate change and government subsidies for agriculture are raising much hope in the adoption of new fertilization recommendations for cultivated crops. These recommendations are better targeted to meet soil and crop needs with a focus on improving yields and productivity. The inclusion of secondary nutrients (Ca, Mg and S) and micro nutrients (B, Zn and Cu) in fertilizer formulas has boosted agricultural yields. Even if soil deficiencies are thought to have been corrected for the cotton and sugar zones in West Africa, and that millet/sorghum, rice and cowpea responses to potassium have been mixed, P and K applications are justified in mineral fertilization formulas. Regarding nitrogen, the basic nutrient in cereal production, split applications in line with the vegetative cycle is a guarantee for maximizing its use by crops and increasing agricultural production. The latest achievements of the OFRA project relating to the optimization of fertilizer recommendations for cereals in Mali raise much hope for a wide adoption by farmers.

Ultimately, the gradual setting up of bulk-blending units in most countries of the sub-region allowing the production of fertilizerformulasby simple mechanical blending should facilitate on-demand fertilization for crops according to specific productionobjectives. Sustained government subsidy for agriculture is the key to the widespread adoption of these new recommendations through lower prices and a high availability of fertilizers.

11.6 Conclusion

In Mali, contrasted agro-ecological zoning has led to a wide diversification of cultivated crops. Due to low inherent soil fertility, technical recommendations are required for organo-mineral fertilization to improve agricultural production and productivity.

The old standard fertilizer recommendations for on major crops have been met with low level of adoption by farmers because of the high cost of mineral fertilizers. The practices of fertilizer under-dosingcombined with agricultural extensification have led to a strong physical, chemical and biological degradation of soils

Today, new fertilizer recommendations that are better suited to soil evolution, cropping practices and crop needs will boost agricultural production despite adverse climatic changes. Ultimately, sustained government subsidies for agriculture and the multiplicity of bulk-blending units would be powerful levers for the widespread adoption of these new recommendations towards a prosperous and sustainable agriculture.

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Chapter 12
Fertilizer Recommendation for Maize, Sorghum, Millet, Cowpea, Soybean and Cotton in Nigeria

I.Y. Amapu, V.O. Chude, and B.D. Tarfa

Abstract Nigeria, like most sub-Sahara Africa countries, is an agrarian country its heavy reliance on petroleum as a major source of income notwithstanding. Fertilizer is one of the most important inputs needed for increased and sustained crop and soil productivity. This is because most of the soils are inherently poorly endowed with many of the essential nutrients required by crops grown in Nigeria. Due to the fact that fertilizers must be used judiciously to ensure good economic returns and minimize any deleterious environmental consequence, there is the need to determine the right source, right rate, right placement method and time of application (4Rs). This is further necessitated by the high spatial variability of Nigerian soils occasioned by diverse rocks from where they are formed, the climate, vegetation and other soil forming factors. Efforts have been made by Agronomists and Soil Scientists since 1937, when inorganic fertilizers were introduced into Nigeria, to ensure that the four Rs of best fertilizer management practices (BFMPs) are put in place. This paper reviews the development in fertilizer recommendations for some selected crops in Nigeria. It ascertained that before a recommendation is made necessary steps such as correlation and calibration studies, and the establishment of critical soil test levels are carried out; such trials result in average recommendations for a crop within an area which are normally put out by approved extension agencies for adoption by farmers. Most of these efforts were aimed at maximizing crop yields while a few studies included information on maximizing profits and providing options for different economic categories of farmers to use this input. The paper posits that to ensure site-specific recommendation, efforts should be geared towards the employment of decision support tools such as Nutrient Expert and Rice

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Advisor, among others and soil tests with innovative tools such as the SoilDoc and other soil test kits.

Keywords Fertilizer recommendation • Site-specific • Soil test

Contents

12.1 Introduction

Agriculture is strategic to the Nigerian economy and plays the key roles of supplying food for the population, raw materials for industries, earning high foreign exchange which is next only to that from crude oil, providing market for the industrial sector and a key contributor to wealth creation and poverty alleviation. About 70% of the population derive their living from agriculture and agro-allied activities, with the sector contributing about 41% of the Gross Domestic Product (GDP) and accounting for 5% of total export.

It is estimated that about 800,000 square km (80 million hectares) of the total land area of Nigeria of 923,000 square km are cultivable but only about 40% is currently under cultivation. Similarly, of the estimated 3.14 million hectares of irrigable land area only about 220,000 hectares (7%) is utilized. Small-scale farm holdings predominate in Nigeria, accounting for 81% of the total area under cultivation and about 94% of agricultural output, with commercial farms producing the remaining balance.

It is generally accepted that the soils are of poor inherent fertility due largely to the fact that soils in Nigeria have formed from the residues of deeply weathered, complex base rocks and alluvial materials under humid to dry tropical conditions. Most of the soils are therefore highly leached resulting in medium to high acidity, moderate to low cation exchange capacity and base saturation, and low organic matter content. The concentration of available levels of nitrogen, phosphorus and potassium are correspondingly low. Many of the soils are susceptible to erosion due to their relatively low nutrient status and organic matter content, and fragile structure. Soil degradation and attendant depressed yields due to nutrient mining, and inadequate soil and moisture conservation practices, has already reached severe proportions in parts of the country. Soil nutrient replenishment from organic and mineral sources is therefore a prerequisite for continuous cultivation of such soils particularly under intensive production. Additionally, Nigerian soils, like most other tropical soils are inherently micro-variable within short distances. This is complicated by geographical location, climatic factors, vegetation, and land use. The implication is that the native soil fertility is not uniform; therefore, any amendment of such soil with exogenous material like fertilizer must be applied with caution after appropriate soil testing and precise calculation to ensure nutrient balancing and cater for environmental concerns. Therefore, there is no scientific basis for extrapolative application of fertilizer, except if the climate and soil grouping is found to be the same across the same region.

The afore-stated facts point to enormous potentials that are yet to be exploited in agriculture. For the potentials to be realized several current Government policies such as deregulation of seed and fertilizer sectors, marketing reforms to structure markets, innovative financing for agriculture, new agricultural investment framework could help propel the action. These however need efficient utilization of inputs such as improved germplasm, fertilizer and water to succeed. Efficient fertilizer use can be achieved when the four Rs of best fertilizer management practices (BFMPs): Right source, Right rate, Right place, Right time of application are adopted. This requires that good fertilizer recommendations that are crop and soil specific be formulated.

This paper is an attempt to review fertilizer recommendation of some crops, their usefulness and shortcomings and way forward for more appropriate proposals that should improve nutrient use, crop and soil productivity.

12.2 History of Fertilizer Use in Nigeria

As in most parts of tropical Africa, the traditional method of maintaining soil fertility and productivity in Nigeria has been the bush-fallow system whereby arable land is allowed to revert to fallow after 3–4 years of continuous cultivation. The growing human population and other socio-economic pressures on available land has made this practice difficult to sustain. Attempts to improve soil fertility by planting legumes and grass fallows have not been popular and are inadequate for higher yielding and nutrient demanding crops and production systems. The use of manures, particularly where there were large numbers of animals, replaced the fallow system and brought into eminence the agricultural value of farm yard manure (FYM), household refuse, and other organic materials. The first recorded indication of the potential values of inorganic fertilizers in Nigeria was in 1937 when it was shown that response of cereal crops to small applications of FYM was matched by the use of single super-phosphate (SSP) containing equivalent quantities of phosphate. The need to apply fertilizer to depleted soils to resuscitate plant productivity heralded fertilizer use experimentation on the response of crops to applied nutrients such as N, P, and K. The combined application of inorganic and organic fertilizers, especially farmyard manure (FYM) has been advocated by Nigerian agronomist; predating the current ISFM paradigm. This is predicated on research results which established that combined application gave significantly higher yields than either the inorganic or farmyard manure alone. The consensus among the scientist is that the FYM be applied once in two to three years of continuous cropping supplemented with small amounts of inorganic fertilizers. The main constraints associated with use of organic fertilizers include the fact that dung production is constrained by the prevalent semi-nomadic husbandry practices. Additionally, the material is often of low quality because very little attempt is paid to the storage and handling.

Widespread adoption of fertilizer began in the late 1970s with the proliferation of Agricultural Development Projects (ADPs), but overall levels of fertilizer use have been too low to compensate for soil nutrient removal. Today, Nigerian farmers have recognized the importance of fertilizers as a n indispensable input in their crop production ventures, albeit numerous problems militating against their desire to use this important input. The current national average NPK use hovers at 18 kg/ha of arable land (World Bank 2016). This situation persists in spite of the numerous efforts such as involvement of private sector to establish manufacturing and bulk blending plants, institution of subsidy and other agricultural programmes aimed at boosting fertilizer use and crop productivity. Agronomists and Soil Scientist have put in tremendous efforts in providing needed information with respect to appropriate fertilizer recommendation for the crops grown in the country. The current fertilizer recommendation in Nigeria are reported in a manual titled Fertilizer Use and Management Practices for Crops in Nigeria, compiled by the National Fertilizer Use Committee under the auspices by the Federal Fertilizer Department of the Federal Ministry Of Agriculture and Rural Development; It is edited by Chude et al. (2012).

While inorganic fertilizer use has boosted soil fertility and crop production, use of wrong types, rates, placements and timing has created challenges. For example, the continuous application of sulfate of ammonium resulted in the gradual acidification of the soils, so its use was stopped in 1969. Low fertilizer use efficiencies are due to inability or unwillingness of farmers to follow the 4Rs of best fertilizer management practices of applying right fertilizer types at the right rate and time to the right place. This, coupled with use of poor germplasm and non adoption of good husbandry practices has created wide yield gaps between breeders' on-station potential yield predictions and realities from farmers' fields.

12.3 How Fertilizer Recommendations Are Derived

Current fertilizer recommendations for sole crops in Nigeria come from extensive laboratory and/or field trials over time and space. After correlation and calibration studies, and the establishment of critical soil test levels, such trials result in average recommendations for a crop within an area which are normally put out by approved extension agencies for adoption by farmers. However, where an approved fertilizer practice is considered inadequate or where no formal recommendation is available, the Fertilizer Use Committee puts forward suggested practices on the basis of existing information, individual or common knowledge and experience. Details of current recommendations have been documented in a monograph titled, *Fertilizer Use and Management Practices for Crops Nigeria* authored by Chude et al. (2012).

The fertilizer recommendations are accompanied by some salient husbandry practices such as appropriate varieties for each agro-ecology, seed rate, time of planting, disease and weed control, fertilizer rate, fertilizer application time and methods. Commonly yields obtainable and yields under good management are also indicated.

Some of the fertilizer recommendations for the crops are further disaggregated based on soil test levels and agro-ecologies. The criteria for soil fertility classes are as defined below:

Low – The value below critical level
Medium – The range above critical level where variable response to fertilizer is expected
High – The range where response is unlikely and fertilization may not be necessary

Categorization of soil test levels of some nutrients used in fertilizer recommendations are as follows:

	Rating for soil fertility classes			
Nutrient	Very low	Low	Moderate	High
Nitrogen (Total N, g kg^{-1})	0.3–0.5	0.6–1.0	1.1–2.0	2.1–2.4
Phosphorus (Bray – 1-P, mg Kg^{-1})	<3	3–7	7–20	>20
Exchangeable. K, (cmol kg^{-1})	0.12 – 0.2	0.21–0.3	0.31–0.6	0.61–0.73
Zinc (DTPA) mg kg^{-1}		<1.0	1.0–5.0	>5.0
Boron (Hot H_2O soluble) mg kg^{-1}	<0.35	<0.35–0.5	0.5–2.0	<2.0

The following Tables are the fertilizer recommendations for the selected crops. All are sourced from *Fertilizer Use and Management Practices for Crops in Nigeria* authored by Chude et al. (2012) (Tables 12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, 12.9, 12.10, 12.11, 12.12, 12.13, 12.14, 12.15 and 12.16).

Fertilizer recommendation to farmers in Nigeria often appears as straight N, P, or K e.g. urea, SSP and muriate of potash. However to make it more convenient for the farmers to apply fertilizer-nutrient needs in one single formulation, the use of compound fertilizer 15-15-15 has been very widely adopted by farmers. In fact over 70% of all fertilizer used in Nigeria today is in the form of 15-15-15. The problem with too much reliance on 15-15-15 is that this fertilizer has low N and P content, and it lacks sulphur or zinc. Yet supplementary sulphur and zinc appear to be necessary for optimum crop performance in many parts of the country, particularly, the savanna grasslands. There is indication that B may also be needed in some parts. The under listed crop and soil fertilizer formulations were developed from Soil Fertility Maps of Nigeria:

The authors of the monograph realize that, whichever of these is produced, there is need to conduct field studies to determine the optimum rates for different crops under different soil fertility conditions. Certain parts of the country may have

Table 12.1 Recommended maize varieties for different agro-ecological zones

Agro-ecological zone		Recommended maize variety
Sahel	Open pollinated Hybrid:	TZSR – Y , TZSR – W, 8644 – 27, 8341 – 58322 – 13, 8425 – 8
Sudan	Open pollinated Hybrid:	As in Sahel + DMRSR – Y, DMRSR – N DMRsR – N
		8341 – 6 8341 – 5, 8322 – 13, 8425 – 8 8644 – 27
Northern Guinea Savanna	Open pollinated Hybrid:	As in Sudan
		As in Sudan
Southern Guinea	Early season	TZSR – Y, TZSR – W, TZB, TZPB, FARZ34, FARZ227
	Open pollinated	FARZ7 WESTERN YELLOW. NCA, NCB
Savanna and Forest	Hybrid:	8329 – 15, 8329 – 22, 8329 – 19, 8425 – 18
		8236 – 17, 8339 – 17, 8428 – 19, 8321 – 18, 8322 – 13
	Late season	DMR-SR-Y, DMR-SR-W, EV8443-SR-W, EV8423-SR-Y
	Open pollinated Hybrid:	8341 – 6, 8341 – 5

Table 12.2 Fertilizer recommendations for maize (open pollinated) (based on soil test/soil fertility map)

Nutrient	Fertility class	Nutrient rates ha^{-1}	Fertilizer rate and source/ha^{-1}
Nitrogen	Low	120 kg N	Urea (260 kg or 5 bags) or CAN (462 kg or 9 bags or 20-10-10) (600 kg or 12 bags). Apply half the rate of N at planting or 2 – 3 WAP and the remaining half at 5 – 6 WAP.
	Medium	60 kg N	Urea (133 kg or 2½ bags) or CAN (231 kg or 4½ bags) or 20-10-10 300 kg or 6 bags)
	High	30 kg N	Urea 63 kg or 1½ bags or CAN 115 kg or 2¼ bags 150 kg 20-10-10 or 3 bags
Phosphorus	Low	60 kg P_20_5	SSP (333 kg or 7 bags) or SSP 3 bags at planting or 2 – 3 WAP
	Medium	30 kg P_20_5	SSP (167 kg or 3 bags) at planting or 2 – 3 WAP
	High	Nil	-
Potassium	Low	60 kg K_20	MOP (100 kg or 2 bags) at planting or 2 – 3 WAP
	Medium	30 kg K_20	MOP (50 kg or 1 bag) at planting or 2 – 3 WAP
	High	NIL	NIL

specific needs that are different from the recommended formulations. Specific formulations may be recommended for such areas.

Most fertilizer recommendations, including those contained in the monograph currently in use in Nigeria were made for maximizing yield and little consideration for maximizing profits. Moreover, current recommendations guiding fertilizer use

Table 12.3 Fertilizer recommendations for Guinea corn (Sorghum) (based on soil test/soil fertility map)

Nutrient	Fertility class	Nutrient rates ha^{-1}	Fertilizer rate and source ha^{-1}
Nitrogen	Low	64 kg N	Urea (142 kg or 3 bags) or CAN (246 kg or 5 bags) or 20-10-10 (320 kg or 6¼ bags)
	Medium	32 kg N	Urea (71 kg or 1½ bags) or CAN (123 kg or 2½ bags) or 20-10-10 or (160 kg or 3¼ bags)
	High	16 kg N	Urea (35 kg or ¾ bag) or CAN (61 kg or 1¼ bags) or 20-10-(10 180 kg or 1¾ bags)
Phosphorus	Low	32 kg P_20_5	SSP (178 kg or 4 bags) or (71 kg or 1½ bags
	Medium	16 kg P_20_5	SSP (89 kg or 2 bags) (36 kg or 1 bag)
	High	NIL	NIL
Potassium	Low	30 kg K_20	MOP (50 kg or 1 bag)
	Medium	15 kg K_20	MOP (25 kg or ½ bag)
	High	NIL	NIL

Table 12.4 Generalized fertilizer recommendations for guinea corn (sorghum) (based on agro-ecological zones)

Agro-ecological zone	Recommendation (nutrient ha^{-1})	Material ha^{-1}
Sahel	**64 kg N**	Urea (142 kg or 3 bags) or CAN (246 kg or 5 bags) 20-10-10 (220 kg or 6½ bags)
Sudan	**32 kg P_20_5**	SSP (178 kg or 4 bags)
Northern Guinea	**30 kg K_20**	MOP (50 kg or 1 bag)
Savanna		
Southern Guinea	**32 kg N**	Urea (71 kg or 1½ bags) or CAN (123 kg or 2½ bags) or 20-10-10 (160 kg or 3¼ bags)
	16 kg P_20_5	SSP (89 kg or 2 bags)
Savanna and Forest	**15 kg K_20**	MOP (50 kg or 1 bag)

in Nigeria were developed over 30 years ago and many are out dated and do not reflect current soil, crop and weather situations. Additionally, these recommendations were formulated from results of soil samples collected from non-geo-referenced sites and, therefore, do not account for the indigenous potential supply of soils, climatic potential of the various AEZs, economic considerations, and fertilizer availability.

While all farmers can profit from fertilizer use, only those with adequate finance may strive to maximize net returns per hectare resulting from fertilizer use. Others need to maximize return on their limited investment. For example by increasing the use and correct application of fertilizer, poor farmers surveyed in Nigeria were able to improve their yields by approximately 30–55%. In turn, they benefited by

Table 12.5 Fertilizer recommendations for millet (based on soil test/soil fertility map)

Nutrient	Fertility class	Nutrient rates ha^{-1}	Fertilizer sources and rate ha^{-1}
Nitrogen	Low	60 kg N	Urea (131 kg or 3 bags) or CAN (231 kg or 5 bags) or 20-10-10 (300 kg or 6 bags)
	Medium	30 kg N	Urea (65 kg or 1½ bags) or CAN (115 kg or 2½ bags) or 20-10-10 or (150 kg or 3 bags)
	High	15 kg N	Urea (32 kg or ¾ bag or (CAN 57 kg or 1 bag) or 20-10-10 (75 kg or 1½ bags)
Phosphorus	Low	30 kg P_20_5	SSP (167 kg or 3 bags) or TSP (67 kg or 1 bag)
	Medium	15 kg P_20_5	SSP (83 kg or 1½ bags) or TSP (33 kg or ½ bag)
	High	NIL	NIL
Potassium	Low	30 kg K_20	MOP (50 kg or 1 bag)
	Medium	15 kg K_20	MOP (25 kg or ½ bag)
	High	NIL	NIL

Table 12.6 General fertilizer recommendations for millet (based on agro-ecological zones)

Agro-ecological zone	Recommendation (nutrient ha^{-1})	Material ha^{-1}
Sahel	60 kg N	Urea (131 kg or 3 bags) or CAN (231 kg or 5 bags) 20-10-10 (300 kg or 6 bags)
Sudan	30 kg P_20_5	SSP (167 kg or 3 bags)
Northern Guinea	30 kg K_20	MOP (50 kg or 1 bag)
Savanna		
Southern Guinea	30 kg N	Urea (65 kg or 1½ bags) or CAN (115 kg or 2½ bags) or 20-10-10 (150 kg or 3 bags)
	15 kg P_20_5	SSP (82 kg or 1½ bags)
Savanna and forest	15 kg K_20	MOP (25 kg or ½ bag)

Table 12.7 Fertilizer recommendations for upland and lowland rice (based on soil test/soil fertility map)

Nutrient	Fertility class	Upland rice	Lowland rice
N	Low	80 kg N	100 kg N
	Medium	60 kg N	80 kg N
	High	40 kg N	40 kg N
P	Low	30 – 40 kg P_20_5	40 – 50 kg P_20_5 "b"
	Medium	30 kg P_20_5	40 kg P_20_5
	High	NIL	NIL
K	Low	30 – 40 kg K_20	30 – 40 kg K_20
	Medium	30 kg K_20	30 kg K_20
	High	NIL	NIL

Table 12.8 Recommended upland rice varieties for the different agro-ecological zones

Agro-ecological zone	Recommended upland rice variety
Sahel	FARO 45, FARO 46 EX-China, FARO 55 (NERICA 1)
Sudan	FARO 45, FARO 46, EX-China, FARO 38, FARO 39 FARO 55 (NERICA 1)
Northern Guinea Savanna	FARO 46, FARO 39, FARO 38, FARO 11, FARO 45 FARO 55 (NERICA 1), FARO 56 (NERICA 2) FARO 58 (NERICA 7), FARO 59 (NERICA 8), FARO 62 (OFADA 1), FARO 63 (OFADA 2)
Southern Guinea Savanna	FARO 46, FARO 48, FARO 49, FARO 43, FARO 41 FARO 55 (NERICA 1), FARO 56 (NERICA 2) FARO 58 (NERICA 7), FARO 59 (NERICA 8), FARO 62 (OFADA 1), FARO 63 (OFADA 2)
Forest	FARO 46, FARO 48, FARO 49, FARO 43, FARO 41 FARO 55 (NERICA 1), FARO 56 (NERICA 2) FARO 58 (NERICA 7), FARO 59 (NERICA 8), FARO 62 (OFADA 1), FARO 63 (OFADA 2)

Table 12.9 Recommended lowland rice varieties for different agro-ecological zones

Agro-ecological zone	Recommended lowland rice variety
Hydromorphic and inland valley swamp	FARO 44, FARO 52, FARO 31, FARO 15, FARO 28, FARO 51 FARO 62 (OFADA 1), FARO 63 (OFADA 2), FARO 60 (NERICA L19), FARO 61 (NERICA L34)
Shallow swamp and irrigated swamp	FARO 44, FARO 52, FARO 51, FARO 27, FARO 29, FARO 37, FARO 60 (NERICA L19), FARO 61 (NERICA L34)
Deep water and floating	FARO 15, CK 73, DA 29, BKN 6986 – 17, ROK 5, IR 54
Mengrove	FARO 15, ROK 5, WAR 77-3-2-2, FARO 28, IR 54

Table 12.10 Fertilizer recommendations for groundnut in different agro-ecological zones

Agro-ecological zones	Recommendation (nutrient ha^{-1})	Material ha^{-1}
All Zones	**54 kg P_20_5**	SPP (300 kg or 6 bags) or TSP (120 kg or 2½ bags)
	25 kg K_20	Muriate of potash (42 kg or 1 bag)
		As above

Table 12.11 Groundnut varieties suitable for different agro-ecological zones

Agro-ecological zone	Recommended groundnut variety
Sahel	Spanish 205, T.47 – 56
	Natal common.
Sudan	Spanish 205, T.47 – 56, 55 – 437 (ex – Dakar) Red Bulk
	Nata common, 55 – 437, 48 – 115B (IAR Cross-breed)
Northern Guinea	Samaru 38, MSS 39, MS 358, DS 5418, RMP 12, M554 – 76
Savanna	MK 374, MS 539, Samaru 61, G.153
Southern Guinea	M.25 – 68*, T.37 – 47
Savanna and Forest	

Table 12.12 Fertilizer recommendations for cowpea and soybean (based on soil test/soil fertility map)

Nutrient	Fertility class	Nutrient rates ha^{-1}	Fertilizer rate and source ha^{-1}
Nitrogen	Low	20 kg N	Urea (44 kg or 1 bag) or CAN (74 kg or 1½ bags) or 20-10-10 (100 kg or 2 bags)
	Medium	10 kg N	Urea (22 kg or ½ bag) or CAN (37 kg or ½ bags) 20-10-10 (50 kg or 1 bag)
	High	NIL	NIL
Phosphorus	Low	40 kg P_20_5	SSP (222 kg or 4½ bags) or TSP (89 kg or 2 bags)
	Medium	20 kg P_20_5	SSP (111 kg or 2 bags) or TSP (44 kg or1 bag)
	High	NIL	NIL
Potassium	Low	20 kg K_20	MOP (33 kg or 1 bag)
	Medium	10 kg K_20	MOP (16 kg or ½ bag)
	High	NIL	NIL

Table 12.13 Fertilizer recommendations for cowpea and soybean (based on agro-ecological zone)

Agro-ecological zones	Recommendation (nutrient ha^{-1})	Material ha^{-1}
Sahel and Sudan	**20 kg N**	Urea (44 kg or 1 bag) CAN (74 kg or 1 ½ bags)
	40 kg P_20_5	20-10-10 (100 kg or 2 bags)
	25 kg K_20	SSP (222 kg or 4½ bags), TSP (89 kg or 2 bags)
		Muriate of potash (33 kg or _ bag)
Guinea Savanna and Forest	**10 kg N**	Urea (22 kg or ½ bag) CAN (37 kg or ¾ bag)
	36 kg P_20_5	SSP (200 kg or 4 bags), TSP (80 kg or 1½ bags)
	20 kg K_20	Muriate of potash (33 kg or _ bag)

making an additional 30–40% profit through greater commodity sales (ProOpCom 2011). Deliberate efforts must therefore be made in ensuring that fertilizer investments give high returns with little risk. This necessitates employment of ingenious techniques for optimizing fertilizer use. Fertilizer use optimization refers to maximizing profit from fertilizer use, including profit per hectare for farmers with adequate finance and profit on the small investment in fertilizer use by the financially constrained farmers. Results from the AGRA funded trial in Nigeria known as Optimizing Fertilizer Recommendations in Africa (OFRA) showed that maximizing net return requires understanding crop response to applied nutrients. The project made use of results of past research (legacy data) which were compiled and analyzed, and additional field research was conducted to improve the information for fertilizer use decisions in the Savanna agro-ecological zones (AEZs) of Nigeria. The food crops addressed were cassava, maize, sorghum, pearl millet, lowland and

Table 12.14 Recommend cowpea and soybean varieties for different agro-ecological zones

Agro-ecological zone	Cowpea variety	Soyabean variety
Southern Sudan	ACCS. 341, 339 – 1, 1768 and 593; IT60, IT84E – 108	TGX 844 – 29D
	ACCS. 355 & 335, ITS4E – 124	
Northern Guinea Savanna	ACCS. 341, 1768, 3391 – 1, 1696	TGX 536 – 02D, SAM Soy – 1, SAM Soy – 2, TGX 855 – 29D
	588/2; IT84E – 108, TVX3236	
	ACCS. 335, 355 and 353	
	Ife Brown, IT84E – 124	
Southern Guinea Savanna	ACCS. 339 – 1 and 341; IT84e – 108 TVX 3236	TGX 536 – 02D, SAM Soy – 1, SAM Soy – 2, TGX 855 – 29D
	ACCS. 335 and 353; Ife Brown IT 84E – 124	
Forest	KANO 1696, Vita 5. Modupe, Ife-Bimpe,	TGM 579, M312, TGX 306 – 036C
	Ife Brown	

Table 12.15 Fertilizer recommendations for cotton

Agro-ecological zones	(Nutrient/ha^{-1})	Material/ha^{-1}
Sahel, Sudan and Northern Guinea Early Crop	60 kg N	Urea (125 kg or 2½ bags) CAN (125 kg or 4 ½ bags) B SPP, 140 kg (3 bags) KCl, 33 kg (1 bag) or 20-10-10 (6 bags) in Boronated SSP
	25 kg P_20_5	
	20 kg K_20	
	0.75 kg Bo	
Late crop	40 kg N	Urea (87 kg or 1¾ bags) CAN (96 kg or 2 bags)
	20 kg P_20_5	
	0.35 B	Boronated SSP (61 kg or (1 bag)
	20 kg K_20	
		KCl (1 bag)
Forest	35 kg N	CAN, 135 kg (3 bags) or SA, 175 kg (3½ bags) or compound (20-10-10) 175 kg (3½ bags)

upland rice, groundnut and soybean. The crop yield responses to applied nutrients were captured in curvilinear to plateau yield response functions as shown in Fig. 12.1 for maize response (vertical axis or y-axis) to applied N (horizontal axis or x-axis) in the Mid-altitude zone. Maize grain yield response to increasing N rates, as exemplified in the Nigerian Mid-altitude AEZ has a steep response at low N rates and a reduced rate of increase at higher N rates until the yield plateau is reached, after which further increase in N rate has little or no effect to increase

Table 12.16 Soil/crop specific fertilizer formulations

States	Fertilizer formulations
Anambra	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes
Abia	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes
Adamawa	(i) NPK: 20-10-10 + 1S + 1Zn for cereals
	(ii) NPK: 10-20-10 + 1S + 1Zn for legumes
Akwa-Ibom	(i) NPK: 20-5-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-5-10 + 1Zn + 2MgO + 2Ca for roots, tubers and tree crops
Abuja	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes
Bauchi	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes
Benue	(i) NPK: 20-10-5 + 1ca + 15 + 1Zn for cereals, cotton and vegetables
	(ii) NPK: 10-20-10 + 1S + 1Zn for legumes
	(iii) NPK: 15-10-10 + 1Ca + 2MgO + 1Zn for roots, tubers and tree crops
Borno	(i) NPK: 20-10-10 + 1S + 1Zn for cereals
	(ii) NPK: 10-20-10 + 1S + 1Zn for legumes
Ebonyi	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes
Edo	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes
Ekiti	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes
Enugu	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes
Cross River	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes
Delta	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes
Bayelsa	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes

(continued)

Table 12.16 (continued)

States	Fertilizer formulations
Gombe	(i) NPK: 20-10-10 + 1S + 1Zn for cereals
	(ii) NPK: 10-20-10 + 1S + 1Zn for legumes
Imo	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes
Jigawa	(i) NPK: 20-10-10 + 1S + 1Zn for cereals
	(ii) NPK: 10-20-10 + 1S + 1Zn for legumes
Kaduna	(i) NPK: 20-5-10 + 1Zn + 1S for cereals and vegetables
	(ii) NPK: 15-5-10 + 1Zn + 1S for roots, tubers and tree crops
	(iii) NPK: 20-5-10 + 1Zn + 1S + 1B for cotton
	(iv) NPK: 10-20-10 + 1S + 1Zn for legumes
Kebbi	(i) NPK: 20-5-10 + 1Zn + 1S for cereals and vegetables
	(ii) NPK: 15-5-10 + 1Zn + 1S for roots, tubers and tree crops
	(iii) NPK: 20-5-10 + 1Zn + 1S + 1B for cotton
	(iv) NPK: 10 -20-10 + 1S + 1Zn for legumes
Kwara	(i) NPK: 20-10-10 + 1S + 1Zn for cereals
	(ii) NPK: 10-20-10 + 1S + 1Zn for legumes
Kogi	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes
Kano	(i) NPK: 20-5-10 + 1Zn + 1S for cereals and vegetables
	(ii) NPK: 15-5-10 + 1Zn + 1S for roots, tubers and tree crops
	(iii) NPK: 20-5-10 + 1Zn + 1S + 1B for cotton
	(iv) NPK: 10 -20-10 + 1S + 1Zn for legumes
Katsina	(i) NPK: 20-5-10 + 1Zn + 1S for cereals and vegetables
	(ii) NPK: 15-5-10 + 1Zn + 1S for roots, tubers and tree crops
	(iii) NPK: 20-5-10 + 1Zn + 1S + 1B for cotton
	(iv) NPK: 10 -20-10 + 1S + 1Zn for legumes
Lagos	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes
Nasarawa	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes
Niger	(i) NPK: 20-10-10 + 1S + 1Zn for cereals
	(ii) NPK: 10-20-10 + 1S + 1Zn for legumes
Ogun	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes
Ondo	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes

(continued)

Table 12.16 (continued)

States	Fertilizer formulations
Osun	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes
Oyo	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes
Plateau	(i) NPK: 20-10-5 + 1ca + 15 + 1Zn for cereals, cotton and vegetables
	(ii) NPK: 10-20-10 + 1S + 1Zn for legumes
	(iii) NPK: 15-10-10 + 1Ca + 2MgO + 1Zn for roots, tubers and tree crops
Rivers	(i) NPK: 20-10-5 + 1Zn + 2Ca for cereals and vegetables
	(ii) NPK: 15-10-10 + 2Ca + 2MgO + 1Zn for roots, tubers and tree crops
	(iii) NPK: 10-20-10 + 1S + 1Zn + 2 Ca for legumes
Sokoto	(i) NPK: 20-5-10 + 1Zn + 1S for cereals and vegetables
	(ii) NPK: 15-5-10 + 1Zn + 1S for roots, tubers and tree crops
	(iii) NPK: 20-5-10 + 1Zn + 1S + 1B for cotton
	(iv) NPK: 10 -20-10 + 1S + 1Zn for legumes
Yobe	(i) NPK: 20-10-10 + 1S + 1Zn for cereals
	(ii) NPK: 10-20-10 + 1S + 1Zn for legumes
Taraba	(i) NPK: 20-10-10 + 1S + 1Zn for cereals
	(ii) NPK: 10-20-10 + 1S + 1Zn for legumes
Zamfara	(i) NPK: 20-5-10 + 1Zn + 1S for cereals and vegetables
	(ii) NPK: 15-5-10 + 1Zn + 1S for roots, tubers and tree crops
	(iii) NPK: 20-5-10 + 1Zn + 1S + 1B for cotton
	(iv) NPK: 10-20-10 + 1S + 1Zn for legumes

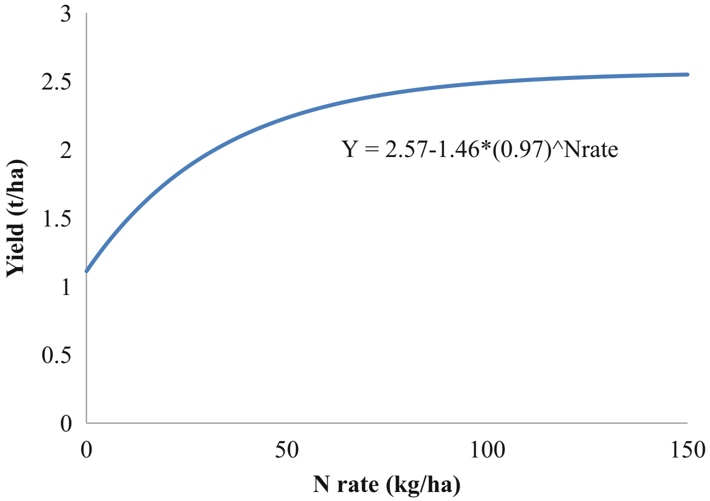

Fig. 12.1 Maize response to nitrogen application in the Nigerian Mid-altitude AEZ

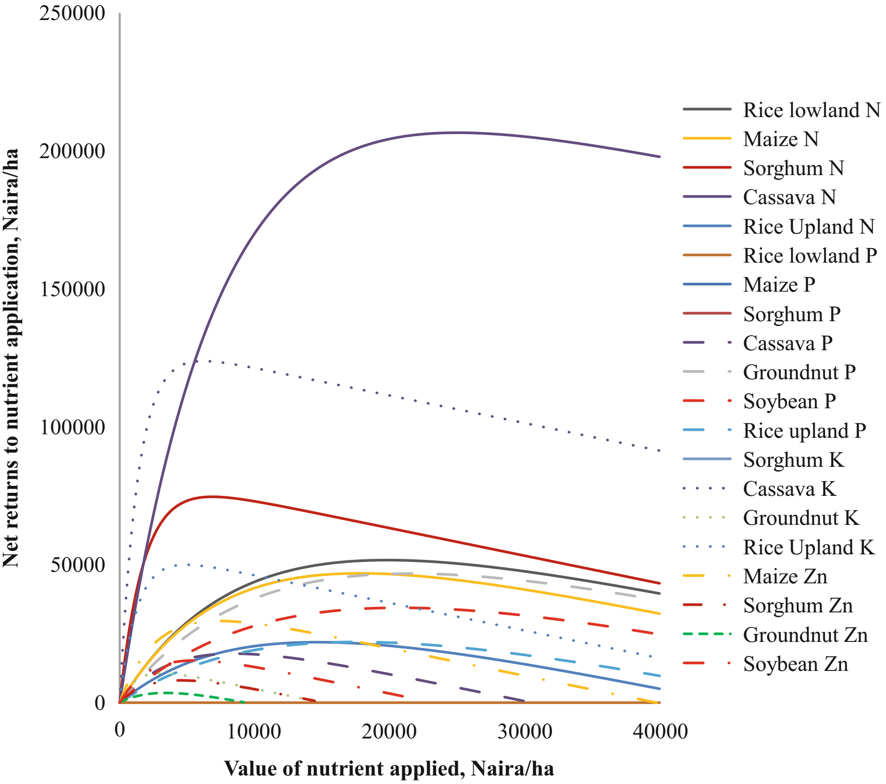

Fig. 12.2 Net returns to investment in nutrients in the Mid-altitude AEZ of Nigeria

yield. There was increasing yields with nitrogen rates up to the 100 kg/ha rate beyond which maize grain yields tends to be constant. The maximum expected yield, on average, was 2.57 t/ha. This type of response to applied nutrients is captured by the equation Yield (kg ha^{-1}) = $\boldsymbol{a} - \boldsymbol{b}\boldsymbol{c}^{\boldsymbol{r}}$, where $\boldsymbol{a}$ is near maximum yield for application of that nutrient, $\boldsymbol{b}$ is the maximum yield increase due to applied nutrient, and $\boldsymbol{c}^{\boldsymbol{r}}$ determines the shape of the curvilinear response. The $\boldsymbol{c}$ is the curvature coefficient and $\boldsymbol{r}$ is nutrient rate. This function shows that the benefit relative to cost for N application is expected to be greater with low N levels compared with high N rate.

Profit potential also varies with different nutrients applied to the same or different crops as shown in Fig. 12.2 for the Nigerian Mid-altitude AEZ. Each curve represents the profit potential of a nutrient applied to a crop. Where the curve of the graph is steep, the net returns to investments are very high and where the curve flattens, the point of maximum profit per hectare is reached. When the graph slopes starts declining, the profit is declining. The results show that it is more economical to invest in N and K applied to cassava than in fertilizers for other crops. Application of low rates of N to sorghum and K to upland rice also have good profit potential. Other crop-nutrient options that are shown have profit potential as well as including the application of very low rate of Zn for groundnut. The resource poor farmer needs to take advantage of the most profitable options first and gradually build financial capacity in order to take advantage of the less profitable choices. Poor farmers will benefit according to their financial ability by operating within the steep slope of the curves where there are high returns from investment, while well-resourced farmers will attempt to apply at economic optimum rate (EOR) to maximize profit per hectare.

The results suggest the need to consider the various crop nutrient response functions in light of their other agronomic choices, the current economics of fertilizer use, and their financial ability. Therefore, easy to use decision tools called fertilizer optimization tools (FOT), which use complex mathematics of linear optimization to reiteratively consider the numerous crop nutrient functions in light of the farmer's agronomic and economic situation, are needed to provide recommendations that maximize returns on investment. It also brings to fore the need for farmers' education on the type of fertilizer they need to procure and use on different crops to maximize profit. Choices of single nutrient and double nutrient compound fertilizers are necessary for optimizing profit. The Fertilizer optimization Tool (FOT) was developed by Jansen et al. (2013). It has been adapted to 67 country-AEZs of Africa including the six savanna AEZs of Nigeria. The FOTs are public goods that can be accessed by individuals at https://agronomy.unl.edu/OFRA.

An example of the type of outputs from this approach is presented in Table 12.17 which shows that the response of upland crops in the Sahel Savanna was greater to applied P compared with N, while lowland rice was more responsive to N. Cowpea and groundnut were not found to be responsive to N but had modest response to applied P and K. The field research based EOR were consistently less and generally less than half the recommended rates. Therefore, even for cases of no financial constraint on the amount of fertilizer use, the recommended rates are well above the most profitable rates, and therefore a profit opportunity is lost in applying according to recommendations. For farmers with financial constraints to fertilizer use, the most profitable rates will be less than the EOR as determined through use of FOTs. These results suggest that most of the national fertilizer recommendations for primary fertilizer elements did not consider economic benefits.

This approach is a step ahead of the one in which only yield maximization is considered. It creates opportunities for farmers to take decisions based on his input purchasing power and preferences; giving him the latitude to take sound economic decisions.

Table 12.17 Sahel savanna, Response functions, expected yield increases (t/ha) for crop-nutrients, and OFRA economically optimal rate (EOR) to maximize profit per hectare compared to current or recent (REC) recommendations by AEZs in Nigeria

Crop	Response coefficients, Yield = a – bc^r; r = elemental nutrient rate				Effect of nutrient rate (kg/ha) on grain yield (t/ha)				Recommended nutrient rate	
		A	B	C	0–30	30–60	60–90	90–120	EOR[a]	Rec[b]
	Nutrient	t/ha			t/ha				kg/ha	
Pearl millet	N	0.742	0.223	0.93	0.198	0.022	0.003	0.000	18	60
Sorghum	N	1.098	0.273	0.97	0.164	0.066	0.026	0.011	24	64
Maize	N	1.275	0.687	0.951	0.535	0.118	0.026	0.006	39	120
Rice, lowland	N	4.461	0.564	0.942	0.470	0.078	0.013	0.002	38	100
					0–5	**5–10**	**10–15**	**15–20**		
Pearl millet	P	1.717	0.768	0.940	0.204	0.150	0.110	0.081	14	13
Sorghum	P	0.975	0.548	0.908	0.210	0.129	0.080	0.049	11	14
Groundnut	P	0.254	0.032	0.87	0.016	0.008	0.004	0.002	0	24
Cowpea	P	0.605	0.109	0.93	0.033	0.023	0.016	0.011	2	17
Maize	P	1.275	0.687	0.951	0.153	0.119	0.092	0.072	0	26
Rice lowland	P	5.19	0.189	0.919	0.065	0.043	0.028	0.018	0	22
Groundnut	K	1.093	0.104	0.800	0.070	0.023	0.008	0.002	10	21
Cowpea	K	0.477	0.063	0.650	0.056	0.006	0.001	0.000	6	17
Rice, lowland	K	6.036	0.223	0.750	0.170	0.040	0.010	0.002	9	33

$P_2O_5 = P \times 2.29$; $K_2O = K \times 1.2$. Some functions have zero response are because of lack of response or lack of information

[a] EOR was determined with the cost of using 50 kg urea and SSP at ₦ 5500 and 4500, respectively. Commodity values (₦/kg) used were: cassava 20, rice 67; maize 50; Sorghum 60; cowpea 165; groundnut 120; soybean 120; and pearl millet 60

[b] Source: OFRA-Nigeria 2015 country recommendation

12.4 Way Forward

While the efforts made in Nigeria is commendable, there is still need for refinement of the information contained in the Tables presented above. The desire is to reach a point where extension workers or farmers can click to coordinates on a map to get fertilizer recommendation for the crop(s) they intend to grow in a season on their farm plot(s).

Most of current fertilizer recommendations in use are therefore largely outdated and still too general ("blanket recommendations"). Its perils and the need for site-specific recommendations have been elucidated in a study on nutrient rationalization in Nigerian compound fertilizers by Adeoye (2006). Youl (2016) listed the following negative consequences blanket recommendation:

- Output/nutrient ratios often below 10 (for cereals) due to blanket recommendations and inadequate method and time of application of fertilizer;
- High fertilizer cost due to the lack of cost-effective fertilizer blends in the market,
- Soil and environmental degradation due to under- or over-application of fertilizer;
- Lack of farmers' confidence in those providing fertilizer and advice.

This is because the soil, crop and climate data used for deriving the fertilizer recommendations above were not sufficient to provide site-specific recommendations.

Site specific recommendations require sufficient quality crop genotype, climate and soil data. Collaborations need to be sought with various new initiatives such as the current development of Nutrient Expert by IPNI, Rice Advisor by Africa Rice and the IITA-OCP project aimed at developing fertilizer recommendations for maize in the corn-belt of Nigeria need to be exploited with a view to compiling and synthesizing information for developing site-specific recommendations. Similarly, the current efforts being made by the African Soil Information Service (AfSIS) and the collaborating country initiatives such as NiSIS, GhaSIS etc should provide needed soil data required for the present efforts.

Nigeria, indeed ECOWAS/CEDEAO should take advantage of new modern soil analysis method such as NIR spectroscopy to generate soil data for site-specific fertilizer recommendations. An investment in soil testing will radically correct the present nutrient imbalances. The savings that will accrue from not overdosing through soil test and wasting nutrients can be channelled to increasing fertilizer quantity that will provide the nutrients needed. The current drive by the FMARD in introducing soil test kits called Soil Doctor through the Department of Climate Change and Agricultural Land Management Services to farmers across the country is commendable.

There is also the need to address problems of using blends or need to move way from blends due to adulteration, segregation, and difficulty in formulating site specific formulations. One of the draw backs in the current use bulk blends in

Nigeria stems largely from the fact that they are transported over long distances. Moreover, use of existing NPKs blends as basal fertilizers have serious limitations because most of them are low analysis fertilizers. While urea has been generally accepted, the original concept of di-ammonium phosphate (DAP) as a basal has been lost. DAP is a very good basal fertilizer as it contains small amounts of N needed after seeding and the P required. If there is a K deficiency, application of MOP (0:0:60) makes sense economically and allows the flexibility to get the K in the right ratio. Farmers can be trained to apply high analysis fertilizers on their own once they know their soils nutrient requirements through soil test. Need for training of extension workers and augmenting them with practicing farmers in their locality; a success story of the innovative use of farmers as extension agents was established recently (Amapu 2014). Where there is the availability of good soil and crop data, bulk blending plants can established to provide site-specific crop and soil fertilizer formulations. It necessarily means that many bulk blending plants need to be established to carter for farms within radii of 100 kilometres. This could bring about the benefits ingrained in using multi-nutrient fertilizers such as ease of handling, transport and storage, ease of application, even distribution of nutrients in the field; and balanced fertilization, i.e. nitrogen, phosphorus and potassium available together from the start and in accordance with plant requirements.

It should be stressed that fertilizers are good for reducing soil fertility problems. However, adding more fertilizer will bring little or no increase in production when other factors are limiting. Excessive use of fertilizers may even reduce yields because it leads to imbalance in availability of nutrients.

Even if adequate applications of fertilizer were made to highly eroded soils, its efficiency would be much curtailed. It becomes extremely difficult to bring the soil back to full production once the top soil is eroded. Although good agronomic practices including fertilizer use may increase the productive capacity of an erosion affected soil, the same methods would have resulted in such larger yields if the soils had not been impaired in the first place. It becomes imperative therefore that adequate soil management and conservation practices be employed in order to sustain crop production at a reasonably high level.

12.5 Conclusion

Stemming from the fact that validation trials indicate that there is a huge variability in crop responses to application of fertilizers within a small area, depending on slopes, landscape positions, soil fertility gradients and crop types. An investment in soil testing will radically correct the present nutrient imbalances. The savings that will accrue from not overdosing through soil test and wasting nutrients can be channeled to increasing fertilizer quantity that will provide the nutrients needed.

Given the diversity of agro-ecologies and soil types, diverse crop types, and crop production systems, there is a need to further strengthen and refine fertilizer recommendations.

There is the need to synthesize existing but scattered research results at a national level; identify knowledge gaps and missing information for further research; create general understanding on the ongoing efforts and agree upon a common research approach in fine-tuning the fertilizer recommendation at local and regional scales.

Fertilizer recommendations should take into cognizance the purchasing power of the farmer and his interests, and aimed at both maximizing yield and profit and therefore the need to employ DSTs that have such capabilities.

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Chapter 13
Improving Agronomic Efficiency of Mineral Fertilizers through Microdose on Sorghum in the Sub-arid Zone of Burkina Faso

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Abstract Maintaining and/or improving soil fertility under conditions of climatic deterioration remains one of the major challenges facing small-scale farmers of the sub-Saharan regions in ensuring their food production. To address this issue, trials combining mineral fertilizer microdosing, MD (2g NPK/seed hole), soil and water conservation (SWC) techniques (zaï associated or not with stone lines or grass strips) were conducted for three years with sorghum (local and improved varieties) on two sites in the north Sudanian zone of Burkina Faso. The main objective of the study was to analyze the effects of the different technology packages tested on sorghum yields and soil chemical characteristics. The results showed that the use of MD technique enabled to double sorghum grain yields. This effect was further enhanced when combined with SWC techniques (45%). The use of the improved sorghum variety increased grain yields by approximately 11%, 70% and 85% when combined with SWC, MD and SWC + MD techniques respectively. Regarding the impact of these technologies on soil fertility, plots developed with SWC techniques showed increases in total organic carbon, nitrogen and phosphorus contents as well as in available phosphorus between 30% and 80%.

Keywords North Sudanian zone • Organic fertilizer • Rainwater management • Soil fertility • Sorghum varieties

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Contents

13.1 Introduction

Sustainable management of agricultural soil fertility has always been a major challenge for farmers in the Sudanian savanna region and particularly in Burkina Faso (Piéri 1992; FAO 2009). Indeed, due to their pedogenetic origin, these soils have low inherent fertility (Lal 2000). The predominance of kaolinite in their clay fraction gives them very low restructuring capacity under natural conditions (Yang and Wei 2012; Phillips et al. 2015) and low water and nutrient retention capacity (Lahmar et al. 2012; Otalvaro et al. 2016). The depth of root soil is very often limited by the presence of a shallow hard pan. Sandy-silty-clayey of texture on the surface, these soils are very sensitive to slacking and runoff. Therefore, their low water holding capacity did not allow them to provide sufficient water to buffer the effects of drought spells often occurring during the growing cycle (Ouattara et al. 2006b; Sermé et al. 2015). Moreover, they showed widespread phosphorus deficiency and very low organic matter content, hardly reaching 1% (Elshout et al. 2001; Lompo 2009). Unfortunately, inappropriate cropping practices and insufficient levels of mineral fertilizers due to the low purchasing capacity of small-scale farmers have led to a drastic decline in soils fertility. As a consequence, soils set off a process of chemical degradation marked by organic matter depletion and increased deficiency in some basic mineral nutrients such as phosphorus. Lompo (2009) showed that the response curve of sorghum to phosphorus is nowadays highly related to agricultural land use intensity.

Given such a production environment on the verge of ecological rupture and the low capacity of farmers to invest in production factors (Bado 2002; Morris et al. 2007; Masse 2007; Tabo et al. 2007; Bagayoko et al. 2011), agricultural research efforts within the Sahelian area have focused on the development of simple and inexpensive packages of Integrated Soil Fertility Management (ISFM). This approach combines rainwater harvesting techniques, efficient use of organic matter and mineral fertilizers and the use of improved germplasm.

The use of mechanical and biological soil and water conservation techniques (stone lines; grass strips; agroforestry; etc.) allowed to disperse runoff and facilitate rainwater infiltration (Zougmoré et al. 2000; Reij and Thiombiano 2003). Studies have shown that in years of rainfall deficit, increases in sorghum grain yield reached 109% against 20% to 50% in years of good rainfall. However; the induced effects of these techniques are even enhanced when they are associated with zaï and/or with organo-mineral fertilization (Zougmoré et al. 2003, 2004a).

The need to improve small-scale farmers' access to mineral fertilizers led to the development of the microdose fertilization technique by some research institutes in the Sahelian area (Buerkert et al. 2001; Aune et al. 2007; Bagayoko et al. 2011). This low cost fertilization technique consists in applying small amounts of mineral fertilizers; from 2g for sorghum to 3g for maize in seed holes or to the feet of the plants after emergence (62.5 to 94 kg. ha^{-1}). It should be highlighted that the recommended fertilizers rates vary between 100 and 150 kg/ha for these two crops in the north-Sudanian zone. Indeed, several studies highlighted the positive agronomic effects of mineral fertilization microdosing technique.

These research works focused on the use of microdosing alone (Tabo et al. 2006; Aune et al. 2007; Bagayoko et al. 2011) or combined with improved germplasm (Palé et al. 2009). However; it is important that this technique which has been tested in some Sahelian countries; be integrated into the ISFM technology packages to be disseminated in similar agroecological zones in West Africa.

Therefore, the present study was conducted in four countries in West Africa (Benin; Burkina Faso; Mali and Niger) to test the effects of inorganic fertilizer microdosing technique combined with soil and water conservation (SWC) techniques and the use of improved seed varieties. In Burkina Faso; the study was conducted in two provinces at the central (Kourittenga) and northern (Zondoma Province) parts of the North-Sudanian zone. These are two zones with relatively contrasting socio-economic and pedoclimatic conditions; and where sorghum ranks first among the cereals grown.

The present article aims to evaluate the effects of inorganic fertilizer microdosing technique, associated or not with SWC techniques on sorghum production and soil physico-chemical characteristics.

13.2 Materials and Methods

13.2.1 Study Sites

The study was carried out on two sites located at the northern (Zondoma Province) and central (Kourittenga Province) parts of the north Sudanian zone of Burkina Faso. The province of Zondoma is situated between 12°38′ and 14°18′ north latitude and 1°33′ and 2°55′ west longitude. Annual rainfall is very variable (500-800 mm). The province of Kourittenga lies between 11°48′ and 12°34′ north latitude and 0°20′ and 0°38′ west longitude. The annual rainfall varies between 600 and 900 mm.

These two sites, characterized by open savannas to wooded parks, are experiencing a more or less advanced degradation of their physical environments. This phenomenon is under the dominant influence of climate (climate variability) and anthropic actions, combined with strong demographic pressure (density of 100 inhabitants/km^2), rudimentary farming systems, extensive animal husbandry. (Ganou 2005; Ouédraogo et al. 2010).

Table 13.1 Technology packages implemented

Technology packages	Factors combined	Study sites	
		Zondoma	Kourittenga
P1	SWC + MO + MD + IV	X	X
P2	SWC + MO + Without MD + IV	X	X
P3	SWC + MO + MD + LV		X
P4	SWC + MO + Without MD + LV		X
P5	Without SWC + MO + MD + IV	X	X
P6	Without SWC + MO + Without MD + IV		X
P7	Without SWC + MO + MD + LV		X
P8	Without SWC + MO + Without MD + LV		X

SWC (Soil and Water conservation technique); *OM* (organic matter); *MD* (Fertilizer microdosing technique); *IV* (Improved seed variety); *LV* (local seed variety)

Most soils are tropical ferruginous soils (CPCS 1967) which are similar to Luvisols and Lixisols according to the classification of the World Reference Base (WRB) for soil resources (FAO 2006). They represent approximately 39% of the soils of Burkina Faso. Of sandy loamy to sandy silty texture, they are very sensitive to compaction and slacking. They are poor in phosphorus and nitrogen and have degraded structures (Ouattara et al. 2006a; Sermé et al. 2015).

13.2.2 Choice and Conduct of Trials

Demonstration trials were carried out from 2011 to 2013 in five villages in the provinces of Zondoma and Kourittenga. Each of thirty farmers (men and women) identified in each province, freely choose a pair of technology packages proposed by the research team. These packages combine SWC techniques; organic fertilization (OM); micro-dose mineral fertilization (MD); local variety (LV) and/or improved variety (IV) of sorghum (Table 13.1). The SWC technique was either stone lines or grass strips associated with zaï.

Zaï holes were dug during the dry season; with spacing of 0.80 m between sowing lines and 0.40 m between sowing holes on the sowing line; i.e. a density of 31,250 pockets per hectare. The zaï holes received uniformly a handful of organic matter (OM) at a rate of about 2.5 tons per hectare.

The amount of fertilizer applied in microdose per sowing hole was 2 g, i.e. 62.5 kg.ha^{-1} of NPK (14-23-14) and 1 g of urea; i.e. 31.2 kg ha^{-1} of urea. NPK and urea were supplied respectively 10 days and 45 days after sowing.

The target crop was either a local variety (Kansiagui; Belko; Kapelga) or the improved variety (Sariaso 11) of sorghum. Sorghum cropping cycle varied between 75 and 110 days for the local varieties against 90 and 100 days for the improved variety.

The size of the elementary test plot was 500 m^2. The experimental design was the Fisher-type with scattered blocks in which each farmer was considered as a replicate and was testing two technology packages.

13.2.3 Yields Evaluation

Sorghum panicles and straw were collected on the elementary plot, after removing the outer two lines and two sowing holes, each side. They were air dried until constant weight. The panicles were then threshed. The grains obtained were weighed.

13.2.4 Soil Analysis

Composite soil samples were collected during the dry season prior to the third year of the trial and on the 0-20 cm soil horizon. Soil chemical analyzes were conducted in the laboratory of the University of Saskatchewan (Canada). pH, cation exchange capacity (CEC), organic carbon, nitrogen and total phosphorus, as well as, available phosphorus were determined using analytical methods adapted to tropical soils.

The pH was determined by the electrometric method (Nelson & Sommers 1982). Determination of organic carbon was done through dry combustion using LECO-C632 (LECO © Corporation 1987); opting for standard references applicable to soils with very low organic matter content.

Soil total nitrogen and phosphorus levels were measured using the standard method of digestion with sulfuric acid and dilution with hydrogen peroxide (Thomas et al. 1967). The diluted total N and P extracts were dosed with an automatic analyzer.

Available phosphorus and CEC were simultaneously evaluated through the Mehlich III method (Mehlich 1984).

13.2.5 Statistical Analysis

Statistical analyzes were carried out using the Mix Model package of Genstat software and the means were compared according to the Chi 2 test. This tool allowed to carry out statistical analyzes on unbalanced experimental devices and in farmers' fields where variability is fairly high.

13.3 Results

13.3.1 Effects of Technologies on the Evolution of Soil Chemical Fertility

Table 13.2 presented the results of the measurement of various soil chemical characteristics. With the exception of pH and cation exchange capacity, soil chemical characteristics were significantly improved (at the 5% probability threshold), following the implementation of the technology packages. Plots developed with SWC techniques, with or without mineral fertilizers, showed increases of 30-40% in nitrogen and available phosphorus and 70-80% in soil organic matter and total phosphorus; compared to treatment without SWC and plots under farmers' practices. However, the latter had higher nutrient content than the demonstration plots that were not under SWC or MD techniques. On the other hand, the pH and CEC did not vary significantly with the treatments, even though the CEC experienced increases due to rainwater harvesting techniques, with or without microdose.

13.3.2 Effects of Technology Packages on Sorghum Production

Tables 13.3 and 13.4 showed the results of the trials carried out during the three years of experimentation in Zondoma and the two year average in Kourittenga.

Table 13.2 Effects of technology packages on soil chemical properties

Treatments	Avail. P (mg kg^{-1})	CEC (cmol kg^{-1})	Total N (mg kg^{-1})	OM (%)	Total P (mg kg^{-1})	pH
Farmer Practices	2.62b	6.13	317bc	0.70bc	127.8b	6.06
SWC+OM+MD +IV	3.04ab	6.41	405ab	0.89ab	161.4a	5.96
SWC +OM+ WMD+IV	4.33a	7.44	454a	1.02a	163.5a	6.16
WSWC +OM +MD+IV	2.34b	5.84	266c	0.54c	101.4b	6.25
WSWC +OM +WMD+IV	1.92b	4.88	249c	0.53c	91.0b	6.08
Fpr	0.03	-	0.001	0.001	0.001	-
Lsd	1.4	-	100	0.21	36	-

WSWC (without soil and water conservation techniques); *SWC* (Soil and water conservation technique); *MD* (Fertilizer microdosing technique); *WMD* (Without fertilizer microdosing technique); *OM* (organic matter); *IV* (improved seed variety); *Avail P* (Available phosphorus); *CEC* (Cation exchange capacity); *N* (Nitrogen); *Lsd* (Least significant difference). Numbers with the same letter are significantly different at the 5% threshold, according to the Chi2 test

Table 13.3 Effect of the different technologies on sorghum yields (kg ha^{-1}) on the experimental site of Zondoma during the three years of experimentation

	2011 (R = 554 mm)		2012 (R = 825 mm)		2013 (R = 649 mm)	
Treatments	Grain	Straw	Grain	Straw	Grain	Straw
SWC + MD	505.2a	2051a	1827a	3848a	1054.9a	3294a
SWC + WMD	246.3c	1700ab	927ab	2992b	986.2ab	2912b
WSWC + MD	357.4b	1498b	1275b	3592ab	859.3b	3033ab
Chi probability	0.02	0.031	0.001	0.002	0.002	0.011
SED	103	234	176	284	214	355

SWC (soil and water and soil conservation technique), *WSWC* (without soil and water conservation technique), *MD* (microdose), *WMD* (without microdose), *SED* (Standard error deviation), *R* (mean annual rainfall) Numbers with the same letter are significantly different at the 5% threshold, according to the Chi2 test

Table 13.4 Effects of different soil quality management techniques on sorghum yields (kg ha^{-1}) at Kourittenga

Treatments	Grain yield	Straw yield
SWC + MD + IV	1426.5a	4518a
SWC + SMD + IV	862.7b	3365a
SWC + MD + VL	772.8bc	3231ab
SWC + SMD + VL	447.2bc	2058b
WSWC + MD + IV	1022.5ab	3699a
WSWC + SMD + IV	334.3c	2091b
WSWC + MD + LV	598bc	3290ab
WSWC + WMD + LV	360c	3040ab
Chi probability	0.001	0.005
Sed	456	1267

MD (Fertilizer microdosing), *WMD* (without Fertilizer microdosing), *SWC* (Soil and Water Conservation), *WSWC* (without Soil and Water Conservation), *IV* (improved seed variety), *LV* (local seed variety). Values with the same letter are significantly different at the 5% threshold, according to the Chi2 test

In Zondoma; sorghum yields varied from year to year and in the same year between treatments. Relatively low in the first year of experimentation, sorghum grain yields increased more than tripled in the second year with all treatments. The average annual rainfalls recorded were 554 and 825 mm; respectively. Despite these inter-annual variations; differences in yields between treatments were significant for any given year. The MD technique associated with SWC techniques proved to be the most productive combination compared to other treatments. This treatment increased grain yields by 105%, 97% and 7% compared to SWC alone, during 2011, 2012 and 2013 respectively. Compared to the treatment using micro fertilization alone, the combination MD + SWC increased grain yields by 41%, 43% and 23% in 2011, 2012 and 2013 respectively. By contrast; without SWC techniques, MD technique induced substantial yield gains in sorghum grain during the first two years. These improvements in grain yields were in the order of 45% and 35.5% in 2011 and 2012 respectively.

Regarding straw production; the differences between the effects induced by the different technology packages were not as clear as those observed on grain production. However, SWC and MD association produced the highest yield.

In Kourittenga, on the other hand, the highest yields in sorghum grain and straw were achieved by combining MD, SWC techniques and the improved variety. However, without SWC techniques, grain yields fell by 39% and 28% respectively with improved and local sorghum varieties. Therefore, microdose combined or not with water harvesting technique, substantially improved sorghum production, irrespective of the variety considered. The lowest yields came from treatments that did not use SWC techniques or mineral fertilizers with any given variety. The use of the improved variety of sorghum increased grain yield by about 11%, 70% and 85% under SWC, MD and SWC + MD techniques respectively. However, the improved variety without any technology produced less than the local one.

Furthermore, just as in Zondoma, there were no significant differences between the induced effects of the technology packages on straw yields, although the values were higher.

13.3.3 Discussion

After three years of on-farm trials, the results of soil chemical analyzes highlighted the need to combine soil and water conservation techniques (SWC) with micro fertilization in order to improve soil fertility and crop productivity.

Soil organic matter contents were significantly improved in plots under rainwater harvesting technique. The improvement in organic status is largely due to the sedimentation of vegetation fragments upstream the stone lines (Zougmoré et al. 2000). It could also be linked to the organic fertilization on the trial plots (Yaméogo et al. 2013). Total nitrogen and phosphorus contents, as well as available phosphorus contents were particularly higher on the plots under SWC techniques. These increases highlighted the crucial role played by SWC techniques (stone lines; grass strips) in the process of Soil organic matter accumulation and mineralization (Zougmoré et al. 2000, 2004a). OM is, among others things, a source of plants nutrients such as nitrogen and phosphorus.

Generally, the gains in soil fertility induced by the combination of SWC and MD techniques, compared to farmer practices highlighted the importance of this technology package in improving soil productivity. Indeed, the implementation of SWC structures was considered as a prerequisite for organo-mineral fertilization (Zougmoré et al. 2003, 2004a).

The relatively high level of the nutrient content of farmers' plots compared to the demonstration trials that did not benefit from fertilizers or SWC techniques could be due to the great diversity characterizing the management of farmer plots' fertility. Surveys carried out among farmers (Traoré 2014) showed that some applied OM and/or mineral fertilizers to plants facing development deficits. This soil fertility management strategy is commonly observed among small-scale farmers in the use of the mineral fertilizers acquired according to their limited financial capacity (Traoré 2014).

The effects of the different technology packages tested on sorghum grain production were determined by rainfall over the three years (Sawadogo et al. 2008). The first year of the trial was characterized by great intra-annual variability evidenced by (i) a late installation of the rainy season; (ii) early cessation of rains and (iii) drought spells during the wet season. The annual rainfalls recorded on the two study sites (554 mm in Zondoma and 641 mm in Kourittenga) were lower than the expected annual rainfall of 8 years out of 10 (686 mm) in the north-Sudanian zone (MED 2006). This resulted in a particularly harsh agricultural season for farmers in the area. The other two campaigns were wetter. This inter-annual and intra-annual variability of rainfall which is highly endemic in the sub-arid regions of West Africa (Stoorvogel and Smaling 1990; Ouédraogo et al. 2010) highlighted the "buffering" or depressing effects of the technology packages tested. Integrated soil fertility management (ISFM) is nowadays the recommended strategy for the sustainable improvement of agricultural production which is plagued by the perverse effects of climatic hazards (Cooper et al. 2008; Twomlow et al. 2010; Sawadogo et al. 2008). The results of this study clearly supported this assessment.

Soil and water conservation techniques combined with organo-mineral fertilization and the use of high-performance plant material led to maximum yields at each of the two study sites. These results were consistent with those of Zougmoré et al. (2004a, b); Bagayoko et al. (2011) in the sub-arid zones of West Africa. Yield gains were all the greater as rainfall was not a limiting factor (Stoorvogel and Smaling 1990; Zougmoré et al. 2003). When the rainfall conditions became severe like in Zondoma, yields have dramatically decreased. At this moment, the combined use of SWC techniques and mineral micro fertilization really expressed; their "buffering" effects against climatic vagaries (Palé et al. 2009). Therefore, fertilizer applications tripled sorghum production whereas the use of SWC techniques doubled it. These results showed, the importance of mineral fertilization in increasing crop production and soil fertility (Buerkert et al. 2001; Zougmoré et al. 2004b; Twomlow et al. 2010; Bagayoko et al. 2011). Similarly, SWC techniques improved the water status of these soils (Botoni and Reij 2009; Zougmoré et al. 2004a) which left alone, could not provide adequate water reserve to buffer the negative effects of the inherent rainfall deficits in the Sahelian area. This is particularly due to their degraded structures and the low depth of their rooting zone due to the presence of underlying hard pans (Ouattara et al. 2006b; Sermé et al. 2016).

The effects of the ISFM techniques were particularly marked during the phases of grain formation and filling as evidenced by the little or no significant difference between straw yields. The beneficial effect of ISFM techniques was supported by the fact that farmers who did not apply any of such techniques had no grain harvested in Zondoma in 2011.

The genetic potential of the plant material further contributed to improving the performance of SWC techniques and/or mineral fertilizers as shown in the results of the trials conducted in Kourittenga. The use of the improved sorghum variety increased grain yields by 11%, 70% and 85%; respectively; compared to the SWC; MD and the SWC+MD combination. This was consistent with the results of previous studies which showed that crop genetic potential affected the effectiveness of SWC techniques (Zougmoré et al. 2003, 2004b). On the other hand, it further enhanced the performance of mineral fertilizers (Palé et al. 2009). Then, an improved variety expressed its potential, when its water and nutrient requirement were met.

Yield reduction was found greater with local varieties (73%) than with the improved variety (65%), when no fertilizer was applied. This may indicate that the local varieties used more efficiently fertilizer in Kourittenga. This finding contrasted that of several research studies led on the subject (Zougmoré el al. 2003). The investigations carried out showed that among the local varieties used by farmers as controls; there was an improved local variety such as Kapelga. This could explain this situation.

13.4 Conclusion

This study confirmed the agronomic efficiency of MD technique enabling to which enables to achieve remarkable yield levels on degraded soils. This technique was enhanced even more by the prior installation of mechanical and/or biological soil and water conservation techniques. Because of the erratic pedoclimatic conditions (soil degraded structure, rainfall deficiency, etc.) of sub arid areas of West Africa, like in Burkina Faso, it was necessary to install some SWC techniques to improve the MD technique. The use of high-performance plant material enhanced the efficiency of SWC techniques. This enhancement was even more pronounced with MD technique. MD technique intervened within an integrated soil fertility management system in which OM played a crucial role. The ex-ante characterization of soil fertility confirmed the agronomic efficiency of these technology packages. It is absolutely essential to show whether investment in these technologies is economically profitable and socially beneficial to the small-scale farmers for whom they were intended.

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Chapter 14
Socio-economic Determinants and Trends on Fertilizer Use in West Africa

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Abstract A large number of people in Africa continue to grapple with food and nutrition insecurity largely due to insufficient food availability, inadequate incomes coupled with high rates of unemployment, risk and vulnerability as well as inadequate access to basic services. The situation has been exacerbated by emerging global socio-economic trends, population increase, land degradation, climate change and an undeveloped agricultural sector among many other causes (Bationo and Egulu, Status of implementation of Abuja declaration, 2013). It is estimated that Africa's 226.4 million people are chronically hungry (FAO 2012).

Food security has been threatened in African countries since the past decades due to the decrease in soil fertility, poor use of improved technology and low investment in agriculture. These had impacted negatively on crop yields, overall agricultural production and development of African countries. The situation has been a concern to African leaders who converged to the Africa Fertilizer Summit of Abuja in 2006 to discuss and prescribe some solutions to remedy the issues. At this meeting, it was noted that Africa has the lowest rate of fertilizer application. The continent has a fertilizer application rate of about 8 kilograms per hectare, which is far below the global average of 50 kilograms per hectare.

A 12-point resolution was therefore developed at the end of the summit that was aimed at achieving the global average of fertilizer use by 2015. The resolution, which was known as the Abuja Declaration on Fertilizer for an African Green Revolution spells out measures and actions that must be taken to accelerate the accessibility, availability and affordability of fertilizers in the region.

On the production side, the average annual increase of cereal yield in Africa is about 10 kg ha^{-1}, corresponding to extensive agriculture neglecting external inputs like improved seeds and plant nutrients (Bationo et al. 2004). Due to a high population growth rate (3%) compared to cereal grain yield (<1%) (Gruhn et al. 2000), cereal production per capita has decreased from 150 kg/person to 130 kg/person over the last 35 years, whereas Asia and Latin America realized per capita food increase from 200 kg/person to 250 kg/ person during the same period.

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Although some effort are underway to improve agricultural productivity in West Africa through the increased use of improved inputs including fertilizers, it is important to notice that food insecurity is still threatening many African countries. Some scientists support that the increase in yields of the food crops has been largely due to land expansion rather than crop productivity improvement potential. There is ample evidence that increased use of inorganic fertilizers has been responsible for an important share of world-wide agricultural productivity growth. Efficient fertilizer use can stimulate production growth, improve food and nutrition security and reduce poverty through income growth for farmers and lower food costs for consumers. Nevertheless production increase in Africa is mainly attributed to area increase than productivity increase (Table 14.1).

Fertilizer was as important as seed in the Green Revolution contributing as much as 50% of the yield growth in Asia (Wigg and Hopper 1993). Several studies have found that one-third of the cereal production worldwide is due to the use of fertilizer and related factors of production (Bumb 1995, citing FAO and Van Keulen and Breman 1990). A diagnosis analysis of fertilizer demand in West Africa showed some level of improvement since the Abuja Summit and more specifically after the food crisis of 2008. For instance, fertilizer consumption in the 15 ECOWAS countries was 1,020,000 tons with an average rate of 9 kg/ha in 2006, while it was estimated in the 8 WAEMU countries plus Chad at 1,025,000 tons with an average rate of 15 kg/ha in 2012 (Mando 2013).

On 30 June–1 July 2013, the Food and Agriculture Organization in collaboration with the African Union Commission, and the Institute Lula convened a high level meeting in Ethiopia, Addis Ababa. The meeting put together African and International Leaders to deliberate and endorse a radical approach to end hunger in Africa by 2025 building on renewed partnerships within the CAADP Framework. The present paper is an attempt to analyze the socio economic determinants of fertilizer use in West Africa since the declaration of Abuja. It will also point out progress made and their impact on agricultural outputs and people livelihood in West Africa. It will be based on recent studies conducted on fertilizer and agricultural outputs in Africa. Some indicators like fertilizer use rate and consumption, economic return of fertilizer use, effect of fertilizer use on natural resources and livelihood, and new trends in fertilizer use will be developed to show progress achieved since the Abuja Summit.

Keywords Fertilizer use • Determinants • Statistics and trends

Contents

14.1 Introduction

According to The Fertilizer Institute (TFI 2002), fertilizers account for more than 50% in the increase of productivity. It contributes to farmers' welfare through the generation of additional incomes. Efficient use of fertilizers can stimulate production growth, improve food and nutrition security and reduce poverty through income growth for farmers and lower food costs for consumers. Fertilizer was as important as seed in the Green Revolution contributing as much as 50% of the yield growth in Asia (Wigg and Hopper 1993). Several studies have found that one-third of the cereal production worldwide is due to the use of fertilizer and related factors of production (Bumb 1995, citing FAO and Van Keulen and Breman 1990). In most part of the word, the average use of fertilizer ranges from 73 kg of nutrients per hectare of arable land in Latin America to 135 kg/ha in East Asia. In West Africa the rate is it recently estimated at only 12 kg/ha (IFDC 2015). Table 14.1 shows some figures and selected African countries.

Sub-Saharan African countries count among the most affected in the world by food shortage and growing poverty. Although the conditions of high demand for fertilizer exist, yields remain low to meet the intensification of agriculture. At the same time, the agricultural yields of major crops have stagnated or declined in Sub-Saharan Africa but it continues growing in other parts of the world.

Some evident factors hinder the effective growth of fertilizer demand and the organization of fertilizer industry. This situation does not facilitate the creation of favorable conditions to supply the fertilizer market effectively. Nevertheless trends in fertilizer use especially in fertilizer consumption and fertilizer use rate have been increasing in West Africa during the last decade.

Many studies have shown the positive correlation between the growth of agricultural productivity and the use of fertilizers (TFI 2002). The situation of low productivity of agriculture in the SSA could have led to increased use of fertilizer. Unfortunately, the market is not properly supplied with required fertilizers and farmers' needs are not fulfilled.

The current study is a compilation of some facts and evidence on improvement in fertilizer use determinants in West Africa and progress made on fertilizer consumption indicators since the Abuja declaration. Statistics on fertilizer use in Africa compared to other parts in Africa and the World have been presented to support the concepts developed. The study also provides with some tracks to improve fertilizer supply and use in Africa.

Table 14.1 Fertilizer use in selected African countries 2006–2011

Country	Area cultivated in 2006 (1000 Hectare)	Total nutrient used (+) in 2006	Nutrient used per ha (kg/ha) in 2006	Area cultivated in 2011 (1000 hectare)	Increase in cultivated land 2006–2011 (%)	Nutrient used in 2012(−) in 2011	Nutrient used per ha (kg/ha) in 2011	Increase in fertilizer used per ha 2006–2011 (%)	Cost of imported fertilizers in 2006 (1000 USD)	Cost of imported fertilizers in 2011 (1000 USD)	Increased in cost of fertilizer 2006–2011 (%)
Algeria	7470	99,172	13	7510	0.53	127,033	17	30.7	33,073	66,137	99.9
Egypt	2605	1,283,931	493	2870	10.2	1,686,880	588	19.2	29,543	81,613	176.25
Morocco	8064	482,639	60	7944	−1.5	577,416	73	21	119,791	150,701	25.8
Ethiopia	12,923	149,111	12	14,565	12.7	316,308	22	83	45,671	75,544	65.4
Kenya	5310	182,489	34	5500	3.67	152,529	28	−17.6	2040	NA	NA
Tanzania	9700	57,115	6	11,600	19.68	102,998	9	50	70,862	129,767	83.1
Zambia	3013	77,372	26	3400	12.8	186,132	48	84.6	79,482	166,745	109.7
Madagascar	3000	7399	2	3500	16.6	11,058	3	50	2113	4498	112.8
South Africa	12,600	818,271	67	12,033	−4.5	748,010	62	−7.4	585,010	725,831	24
Burkina Faso	4700	63,000	13	5700	21.3	61,004	11	−15.3	20,336	48,272	137.3
Ghana	4200	84,251	18	4860	15.71	137,533	28	55.5	NA	NA	NA
Mali	5677	99,355	18	6860	20.8	174,437	25	38.8	73,522	174,437	137.2
Nigeria	37,000	369,431	10	36,000	−2.7	151,999	4	−60	247,424	71,018	−71.2
Malawi	3300	117,657	36	3600	9.1	107,435	30	−16.6	35,622	209,179	487.2
Total	**119,562**	**3,891,193**	**32.5**	**125,942**	**5.3**	**4540,772**	**36.1**	**11.4**	**1,344,489**	**1,903,742**	**41.5**

Source: From FAO and from various countries' studies; data compiled by Bationo and Klutse

14.2 Facts on Fertilizer Use in West Africa

14.2.1 Economic Return of Fertilizer Use

Widespread adoption of fertilizer depends on its profitability, which depends on input and output prices as well as on the strength of the fertilizer response.

Pieri (1989) reporting on fertilizer research conducted from 1960–1985, confirmed that inorganic fertilizers, in combination with other intensification practices, had tripled cotton yields in West Africa from 310 to 970 kg ha^{-1}. Table 14.2 summarizes historical data on the yield potential associated with fertilizer use for the main food crops in different agro-ecological zones of Africa, comparing results from (1) on-station trials representing maximum fertilizer response, (2) on farm trials representing intermediate results, and (3) farmers traditional practices using no fertilizers.

From the above, it appeared that maize can increase by 650% over control in farms conditions without fertilizers compared to yield in research station and by 340% in farmers' field conditions with fertilizer use. Other crops' yield like rice can increase from two to four folds over control in farmers without fertilizer compared to fertilizer use in farmers' field using fertilizers and on research station. Increase with cassava using fertilizers is also high as illustrated in the mentioned table.

In a comprehensive review of fertilizer response and profitability research in Africa, Yanngen et al. (1998) found that contrary to conventional wisdom, there

Table 14.2 Yield potential with fertilizer use in West Africa

Crop	Actual yields in farms without fertilizer (Control)	Yield on-station with fertilizer (Kg/ha)	Increase over control (%)	Yield in farmers' field with fertilizer(Kg/ha)	Increase over control (%)
Irrigated rice West Africa (kg/ha)	3000	8000	167	6000	100
Upland rice West Africa	1000	4000	500	2500	150
Low land rice West Africa	1500	5000	233	3000	100
Cassava West Africa	8000	47,000	487	35,000	337
Maize West Africa	800	6000	650	3500	337
Sorghum West Africa	600	3000	400	1800	200
Cowpea-West Africa	300	2000	567	1000	233

Source: Bationo et al. (2013)

Table 14.3 Percentage annual increase in crop yields of selected food crops due to land expansion and crop improvement potential in West Africa

Crops	Area (%)/year	Productivity (%)/year	Production (%)/Year
Cassava	2.6	0.7	3.3
Maize	0.8	0.2	1.0
Yam	7.2	0.4	7.6
Cowpea	7.6	−1.1	6.5
Soybean	−0.1	4.8	4.7
Plantain	1.9	0.0	2.0

Source: www.fao.org

Table 14.4 Fertilizer incentives; Summary of key indicators by crop and region

		Kg of output/kg of nutrient use (Agronomic Efficiency)			Profit Incentives (V/C Ratio)	
Type of crop	Region	Typical	Min	Max	Min	Max
Maize	East & Southern Africa	17	2	52	1	15
	West Africa	15	0	54	0.69	26
	Latin America	10	5	18	1.2	5.3
Cotton	East & Southern Africa	5.8	0	7	0.00	3.1
	West Africa	5	2	12	0.61	3.7
Rice (irrigated)	West Africa	12	7	16	1.6	3.97
	Asia	11	7.7	33.6	1.5	3.1
Sorghum	East & Southern Africa	10	4	21	1.5	2.6
	West Africa	7	3	14	1	18
	Latin America	7	2.8	21		

Source: Adapted from Yanngen et al. (1998)

were numerous examples of fertilizer response and profitability in Africa that compared favorably to those in other parts of the world. The typical and maximum kilograms of output per kilogram of fertilizer (a measure of agronomic efficiency) for rice and maize research reviewed by Yanngen et al. (1998) were frequently equal to or higher than responses obtained in Latin America and Asia respectively. But production increase was largely due to land increase rather than yield increase as shown in Table 14.3.

Maximum value/cost ratios (an indicator of potential profitability) for maize were as high as 26 and those for rice were 4; both were well above a value/cost ratio of 2 used as a threshold level of profitability thought to stimulate on-farm fertilizer adoption. The column 6 in Table 14.4 showing the minimum value/cost ratios obtained for different crops illustrates, however, one of the key fertilizer adoption challenges for Africa that is the risk factor. The low level of minimum VCR explains in some extends farmers' aversion for fertilizer use. This is mainly due to the non mastery of climate conditions in agriculture that limits farmers' investments in any production system without water control.

Some key indicators are used to measure the profitability of fertilizer use:

- the input/output ratio assesses the agronomic efficiency of fertilizer;
- the value/cost ratio uses only the cost of fertilizer that enables an increase of a certain amount of yield, and
- the benefit/cost ratio uses fertilizer and associated costs such as application labor, transport, and additional harvest labor. It is calculated by dividing the total discounted *value* of the benefits by the total discounted value of the costs.

The Tables 14.5 and 14.6 show that agronomic efficiency is two folds higher at research station than on farm level for all cultivated types of rice. The VCR ranges from a minimum amount of 2 at harvest in farm conditions to a maximum value of 6 on station at the highest market price for all cultivated categories of rice. These values express low risk in using fertilizer for all cultivated rice and emphasize on the profitability of fertilizers use on rice. For the BCR that ranges from 0.9 to 5.4 there is very little risk to lose money but high opportunity to get profit by using fertilizer on all categories of cultivated rice. For cassava the three indicators show some high return potentials through the use of appropriate fertilizers. In microdosing conditions where little fertilizers are used, the three indicators point out profit by using fertilizers but with low returns showed by the BCR values and high potential profit with VCR on all types of crops.

14.2.2 Environmental Analysis of Fertilizer Use

Soil nutrient depletion is a major bottleneck in increasing land productivity in the region and has largely contributed to poverty and food insecurity. Soil nutrient depletion occurs when nutrient inflows are less than outflows. Nutrient balances are negative for many cropping systems indicating that farmers are mining their soils of nutrient reserves. The negative effects of nutrient outputs exceeding inputs, manifested in negative nutrient balances and the deficiencies of major nutrients are attributed primarily to non-useful outflows such as burning/removal of biomass, leaching, volatilization, erosion losses of nutrients and the lack of water and waste recycling in agricultural systems.

Considerable export of nutrients is through harvestable products that are the goal and objective of agricultural production. Results from Nutrient Monitoring (NUTMON) (Gachimbi et al. 2002) studies demonstrate that for efficient return to increased agricultural production, enhanced nutrient availability will have to initially depend on the extent to which farmers minimize or eliminate non-useful outflows including residue burning, the loss of nutrients especially N through leaching, volatilization and denitrification and through loss of nutrients by erosion.

Nitrogen is commonly deficient and limits crop production in cultivated soils of the tropics (Sanchez 1976). For most farmers in SSA, the use of mineral N fertilizers is limited due to the high prices and low profitability (Mclntire and Fussel 1986). One of the options is to source N from organic inputs, intercropping and

Table 14.5 Yield response and profitability indicators for rice and cassava in West Africa

Variables	Irrigated rice	Upland rice	Lowland rice	Cassava West Africa
1. Crop Yield Without Fertilizer (Kg/ha)	3000	1000	1500	8000
2. Crop Yield With Fertilizer: - On-Station (Kg/ha)	8000	4000	5000	47,000
3. Crop Yield With Fertilizer: - On-Farm (Kg/ha)	6000	2500	3000	35,000
4. Quantity of N, P205, K20 Applied (Kg/ha)	120 N, 60P205, 0 K20	60 N, 69P205, 36 K20	60 N, 69P205, 36 K20	60 N, 92P205, 48 K20
5. Total Nutrients (Kg)	180	165	165	200
6. Type of fertilizers (e.g. urea, DAP etc.. . .)	Urea, Dap	Urea, NPK (15-15-15)	Urea, NPK (15-15-15)	Urea, TSP, KCL
7. Agronomic Efficiency:- On-Station (Kg/Kg)	27.8	18.2	21.2	195.0
8. Agronomic Efficiency:- On-Farm (Kg/Kg)	16.7	9.1	9.1	135.0
9. Cost of Fertilizer Applied ($/ha)	225	186	186	300
10. Other cost associated with fertilizer used ($/ha)	9	9	9	20
12. Price of Crop at Harvest ($/Kg)	0.2	0.3	0.3	0.2
13. Price of Crop at the highest market price ($/Kg)	0.3	0.4	0.4	0.3
14. Value cost ratio:- On-station at harvest	4.3	3.8	4.5	24.4
15. Value cost ratio:- On-station at the highest market price	6.4	5.4	6.3	36.6
16. Value cost ratio:- On-farm at harvest	2.6	1.9	1.9	16.9
17. Value cost ratio:- On-farm at the highest market price	3.8	2.7	2.7	25.3
18. Benefit cost ratio on station at harvest	3.3	2.8	3.5	23.4
19. Benefit cost ratio on station at the highest market price.	5.4	4.4	5.3	35.6
20. Benefit cost ratio on farm at harvest	1.6	0.9	0.9	15.9
21. Benefit cost ratio on farm at the highest market price.	2.8	1.7	1.7	24.3
22. Scientist providing the data	Bado	Bado	Bado	Fening

Source: Adapted from Bationo and Egulu (2013), Tabo et al. (2006), Tabo et al. (2007)

Table 14.6 Yield response and profitability for Burkina Faso legumes using recommended and microdose fertilizer technologies

Variables	Cowpea recommended	Cowpea Microdose	Groundnut recommended	Groundnut Microdose
1. Crop Yield Without Fertilizer (Kg/ha)	600	600	650	650
2. Crop Yield With Fertilizer: -On-Station (Kg/ha)	1700	1700	1500	1500
3. Crop Yield With Fertilizer: -On-Farm (Kg/ha)	800	1200	1200	1200
4. Quantity of N, P205, K20 Applied (Kg/ha)	14 N	8.7 N	14 N	8.7 N
	23 P205	14 P205	23 P205	14 P205
	14 K20	8.7 k20	14 k20	8.7 K20
5. Total Nutrients (Kg)	51	31	51	31
6. Type of fertilizers (e.g. urea, DAP etc.. . .)	14-23-14	14-23-14	14-23-15	14-23-14
7. Agronomic Efficiency:-On-Station (Kg/Kg)	21.6	35.5	16.7	27.4
8. Agronomic Efficiency:-On-Farm (Kg/Kg)	3.9	19.4	10.8	17.7
9. Cost of Fertilizer Applied ($/ha)	40	25	40	25
10. Other cost associated with fertilizer used ($/ha)	10	10	10	10
12. Price of Crop at Harvest ($/Kg)	0.3	0.3	0.6	0.6
13. Price of Crop at the highest market price ($/Kg)	0.8	0.8	1.2	1.2
14. Value cost ratio:- On-station at harvest	7	10.1	10.2	14.6
15. Value cost ratio:- On-station at the highest market price	17.6	25.1	20.4	29.1
16. Value cost ratio:- On-farm at harvest	1.3	5.5	6.6	9.4
17. Value cost ratio:- On-farm at the highest market price	3.2	13.7	13.2	18.9
18. Benefit cost ratio on station at harvest	6	9.1	9.2	13.6
19. Benefit cost ratio on station at the highest market price.	16.6	24.1	19.4	28.1
20. Benefit cost ratio on farm at harvest	0.3	4.5	5.6	8.4
20. Benefit cost ratio on farm at the highest market price.	2.2	12.7	12.2	17.9
21. Scientist providing the data	Taonda	Taonda	Taonda	Taonda

rotations with N fixing crops and through managed fallows using improved leguminous fallows (Tian et al. 2001). It is also often reported that the inadequate use of mineral sources of nitrogen adversely affects soil structure (Klutse 2008).

Another negative effect often pointed out by agricultural products are health issues. Although fertilizers can modify the structure of agricultural products, there is no tangible study that reveals the direct negative effect of nutrients on human health. Nevertheless some literatures emphasized on the heavy metal residues from fertilizers in soils and products that have negative effect on human health. There is need to enhance quality control mechanism in the region to check the level of any negative item in fertilizers that can affect human being (Klutse et al. 2012).

14.2.3 Gender Issue in Fertilizer Use

The *State of Food and Agriculture 2010–2011* estimates the female share of the agricultural labor force at almost 50%. Prospects for increasing agricultural productivity require taking into account needs of women not least productive inputs namely, fertilizer, land and labor, credit and information services. Considering that women farmers are still vulnerable in farming as in other labor markets, it would be strategic for Member States to address the fertilizer needs of women, for example by special packaging in smaller affordable bags, targeted vouchers or even credit.

Similarly, other specific categories such as youth, vulnerable groups and civil society organizations requirements should be considered. Another aspect of fertilizer use in West Africa is cultural behavior linked to risk aversion for failure in using fertilizers (Klutse 2013). Risk aversion is a threat that is often viewed by small scale farmers as too great to take without some type of insurance or risk mitigation assistance. This social attitude is in link with a low level of control on production conditions like rainfall, floods, drought, and plant diseases. This attitude limits the use of fertilizers and is correlated with low purchase power of the majority of producers in SSA.

14.3 Trends in Fertilizer Use in West Africa

In 2006, The Abuja Summit stated that Africa's fertilizer use averaged only 8 kilograms per hectare, that was only 10% of the world's average. To improve the situation, the African Union Member States resolve to increase the level of use of fertilizer from the current average of 8 kilograms per hectare to an average of at least 50 kilograms per hectare by 2015. Since the end of the Summit, fertilizer consumption indicators have recorded some changes. Through the concepts of availability, accessibility and affordability, various indicators that characterizing trends in fertilizer use will be presented in West Africa.

14.3.1 Availability

The concept availability determines the amount of fertilizers that is physically supplied in a geographical coverage for the need of an intended users. It can be captured through the importation and the balance of previous agricultural campaigns.

Most West African countries are net importers of fertilizers. Apart Senegal and Nigeria who produce part of their fertilizer needs, West African countries import fertilizers for their agricultural production needs. Yearly imports are based on the estimate of needs. Recent assessment on fertilizer subsector in West Africa revealed that the imported volumes are almost below the potential demand of the users. This is expressed in the Table 14.7 where less than 50% of fertilizer requirements are covered in some countries. Another study on fertilizers demand and supply showed that in 2012/2013, total consumption in eight West African countries and Tchad on cotton and cereals is about 769,500 metric tons. Total demand was estimated at 2,219,000 in 2015 metric tons based on area cultivated and was covered at about 31% by the supplied quantities. These examples illustrate that there are enough gaps not covered by fertilizers available in many West African countries. (Table 14.8)

Although the current available quantities do not meet users entire needs, it is useful to mention that there are enough progress in the quantities made available at country level through importation. Table 14.9 shows that many countries have progressed in their quantities made available within 5 years. In Ghana for instance average increase rate is 140% between 2005 and 2010 while it is 98% in Mali (Klutse et al. 2012).

14.3.2 Accessibility

Fertilizer consumption is still low in West Africa. This is due to financial weakness of major producers that are smallholder farmers, climatic risks, economic instability of producers due producer price volatility, and lack of conducive politic incentives (Doumbia et al. 2005; Tabo et al. 2005; Zoundi and Hitimana 2007). Furthermore, the unequal distribution of available fertilizers in the country reduces access to smallholder farmers. In these countries, almost all the major importers and distributors are based in large urban centers or areas of agricultural production.

It is also observed the supply is closely linked to seasons of production (dry season versus rainy season, small versus large agricultural seasons) and to post raining season program of production. The preference of some importers and distributors for some specific geographical zones for their cash crop activities limit access of fertilizers to other users. In general, rural infrastructures like road qualities and warehouses availability are key to fertilizer accessibility in various

Table 14.7 Key indicators of fertilizer availability in West African selected countries

Items	Countries							
	Benin	Burkina Faso	Côte d'Ivoire	Ghana	Mali	Nigeria	Senegal	Togo
Import/Consumption	70,000	150,000	450,000	380,000/200,000	300,000	1,015,400	95,000	70,000
Country fertilizer demand	250,000	300,000	–	400,000	730,000	1,667,000	500,000	200,000
Potential Gaps	180,000	150,000	–	200,000	430,000	652,000	405,000	130,000

Sources: Benin: AIC et CAI. In Rapport Etude Engrais UEMOA, 2012 / Côte d'Ivoire: Komena Boniface, Etude engrais UEMOA, 2012 / Ghana: PPRSD and CRS, 2014 / Mali: DNA, 2014 / Nigeria: FFD, 2013 / Sénégal: Etude de faisabilité de l'UEMOA, 2012 / Togo: Etude UEMOA, 2013 /Nigeria potential needs 4,871,580 mt - APMEU, 1990.Expressed total fertilizer requirement in 2013 is 1,667,243 mt

Note: Consumptions are not well defined in countries. Volumes recorded are most of the time related to import in countries or are trough estimates

Table 14.8 Quantity of fertilizers imported and average needs coverage rate

Country	Import (Average 2010–2012) (Tons)	Distribution by crops (%)		Demand yearly (2015) (Tons)	Coverage rate of demand (%)
cotton + cereals			Non cotton value chain		
Bénin	45,000	95	5	210,000	21.4
Burkina Faso	160,000	78	22	414,000	38.6
Côte-d'Ivoire	63,000	NA	NA	NA	NA
Guinée Bissau	4000	0	100	23,000	17.4
Mali	310,000	52	48	724,000	42.8
Niger	40,000	0	100	198,000	20.2
Sénégal	54,000	72	28	70,000	77.1
Togo	46,000	80	20	250,000	18.4
Tchad	47,500	84	16	330,000	14.4

Source: Mando (2013) – WAEMU, ECOWAS study

Table 14.9 Fertilizer consumption rate by country

Country	Year 2008	Year 2012	Source
Ghana	6 kg per hectare of arable land	Application rate is 12 kg per hectare of arable land	2008 from FAO data and 2012 data from MOFA
Burkina Faso	5 kg per ha of arable land	12 kg per ha	2008 data from FAO and 2012 data from Ministry of agric
Mali	9 kg per hectare of arable land	13 kg/ha in 2012	2008 data from FAO and 2012 data from Ministry of agric
Nigeria	7 kg per hectare of arable land	Not available	From FAO data
Niger	1 kg per hectare of arable land	6 kg per hectare of arable land	From FAO data and 2012 from IFDC

Source: From various sources specified in column 4
NB consumption rate as kg of nutrient per arable land

parts of each country. The network of fertilizer distributors and agrodealers also determines access to smallholder farmers.

Access to fertilizers on time also determines the level of accessibility to farmers. The government subsided fertilizers (prices range between 500 to 600 USD per ton) are available but often come late and are for only a few farmers. Even when they can afford it, they wait to see what they might get from the government The process of distribution is delayed and affects planting on time. Most of the time, agrodealers don't have them on time. Although the subsidy programs seem useful, it usually distorts incentives for farmers to buy fertilizers on time. Table 14.10 shows the level of subsidy in selected countries in West Africa and Tchad (Mando 2013).

Without the subsidies, the cost would all have been borne by the farmers. Nonetheless, the implementation of fertilizer subsidies has been abused. For example, it has been reported that in Senegal and Mali, the implementation was fraught

Table 14.10 Cost of fertilizer, Cost paid by farmers and Subsidy percentage in selected West African Countries 2011/2012

Pays	Cost of fertilizer (FCFA/kg)	Cost to farmers (FCFA/kg)	Level of subsidy (%)
Benin	398	200	50
Cote d'Ivoire	353	265	25
Guinea-Bissau	600	225	62.5
Senegal	506	380	25
Togo	368	184	50
Burkina	509	255	50
Mali	500	250	50
Niger	407	244	40
Chad	500	300	40
Average	441	260	41

Source: GRAD/UEMOA report 2013

with problems of delayed delivery, delayed payments by government to suppliers, non-transparent bidding processes ending with awards granted to firms who were political supporters of those in power, inappropriately large quantities of subsidized fertilizer going to large scale farmers instead of the target group of small scale farmers.

Although the programme had good intentions, the consequences have led a large segment of the farming population in Senegal, particularly in the rice production zones, to advocate for its elimination. This is so because farmers believe they can access fertilizer on the open market at prices equal to or below the "subsidized" prices demanded by the government. Part of the problem is that the government prices are inflated because suppliers must sell to government at a higher price to cover the uncertainties of (i) payments that are delayed more than a year (incurring significant financing charges) and (ii) unreasonably high import and transport costs because the orders are placed so late in the season (Klutse 2013).

14.4 Cost of Fertilizers and Fertilizer Pricing

According to many farmers, the high costs of fertilizers (1000–1200 USD per ton when not subsidized by the government) limit its use. From the time of the Abuja Declaration in 2006 to 2011, the cost of fertilizer increased of 41.5% over a five year period while the cost of imported fertilizers doubled in at least 5 of the selected 14 countries. Whereas farmers in the United States of America (USA) pay USD320/T, the famers in Malawi pay USD1100/T. Whereas the cost of NPK was 250 CFA/kg in 2006 (equivalent of USD 500 per ton), the cost increased up to USD1000 per ton in 2012. It is about 600 USD per ton in 2016 subsequent to severe decrease in oil price. The increase in the cost of raw materials used partly explains

Table 14.11 Farm gate prices of fertilizers in selected African countries as compared to the United States of America (USD/T) 2012

Country	Farm gates prices (USD/T)	Increase (%)
United States	320	–
Benin	507	58
Burkina Faso	735	130
Cote d'Ivoire	801	153
Ghana	577	80
Niger	696	118
Mali	830	159
Kenya	850	166
Malawi	1100	254
Mozambique	1150	254
Rwanda	800	123
Tanzania	1000	212
Uganda	1100	244

Source: various

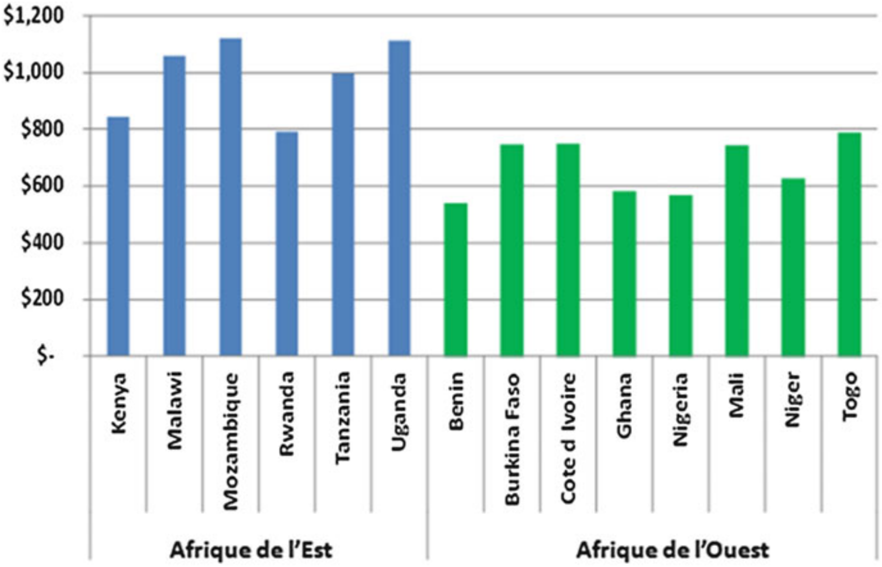

Fig. 14.1 Comparative price of Urea in East and West African countries

the doubling in the cost of NPK in 2011/2012. The percentage price increase as compared to the USA varies from 58 to 254 (as illustrated in Table 14.11).

The price of Urea which is commonly used is equally high. The retail price in April 2012 is between 580 and 800 USD per ton in West African countries against 525 to 1100 USD per ton in East African countries (Fig. 14.1, Table 14.12)

14.5 Fertilizer Cost Structure

In West Africa, CIF (Cost, Insurance and Fret) is the major component of fertilizer price. It range from 50% to 84% of fertilizer price. Table 14.13 and Fig. 14.2 show the main components of fertilizer price in selected West African countries. It is observed that some countries provide fertilizer at better price to farmers but get worst CIF quote on the international market. The figures indicate that some landlocked countries like Burkina Faso and Mali were able to get better CIF quote than those where fertilizers transit from like Togo, Benin and Côte d'Ivoire. This can be explained by the power of negotiation linked to the quantities ordered and the period where fertilizers are ordered. (Fig. 14.2)

Table 14.12 Average price of fertilizers in 8 West African countries and Tchad within the period of 2005 to 2012 (market price in FCFA)

Year	NPK price (FCFA/kg)	UREA (FCFA/kg)	DAP (FCFA/kg)	Average price (FCFA/kg)
2005/06	270	258	235	255
2006/07	276	255	236	255
2007/08	294	326	319	313
2008/09	377	361	429	389
2009/10	402	359	335	365
2010/11	453	463	500	472
2011/12	456	432	500	462
Average price	***361***	***351***	***365***	***359***
Increase rate (%)	***9,5***	***9,8***	***16,2***	***11,8***

Source: GRAD, WAEMU 2013

Table 14.13 Fertilizer price structure in selected West African countries and Tchad

Country	Retailer price (FCFA/kg)	CIF (Price at country gate) (FCFA/kg)	CIF in percent of retail price (%)	Gross margin in percent of retail price (%)
Bénin	398	310	77,9	22,1
Burkina Faso	509	277	54,4	45,6
Mali	500	248	49,6	50,4
Togo	368	309	84,0	16,0
Tchad**	500	323	64,6	35,4
Average	**455**	**293**	64,4	35,6

Source: GRAD, WAEMU 2013

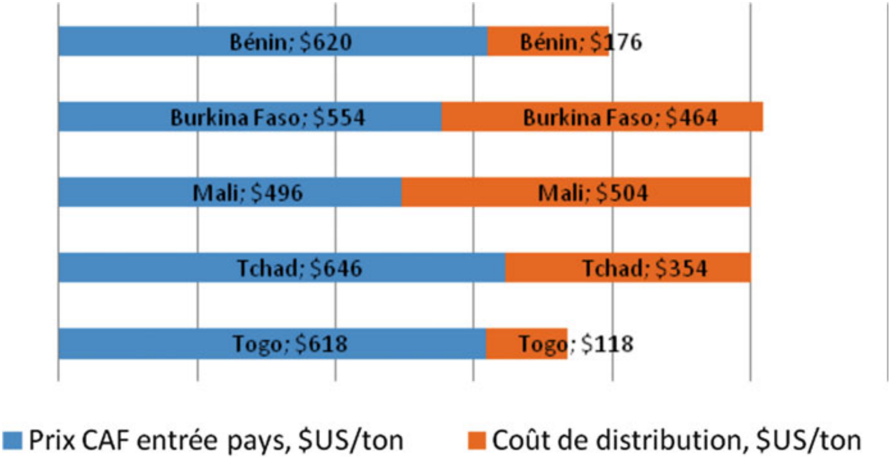

Fig. 14.2 CIF compared to distribution cost in Fertilizer price in West African selected countries

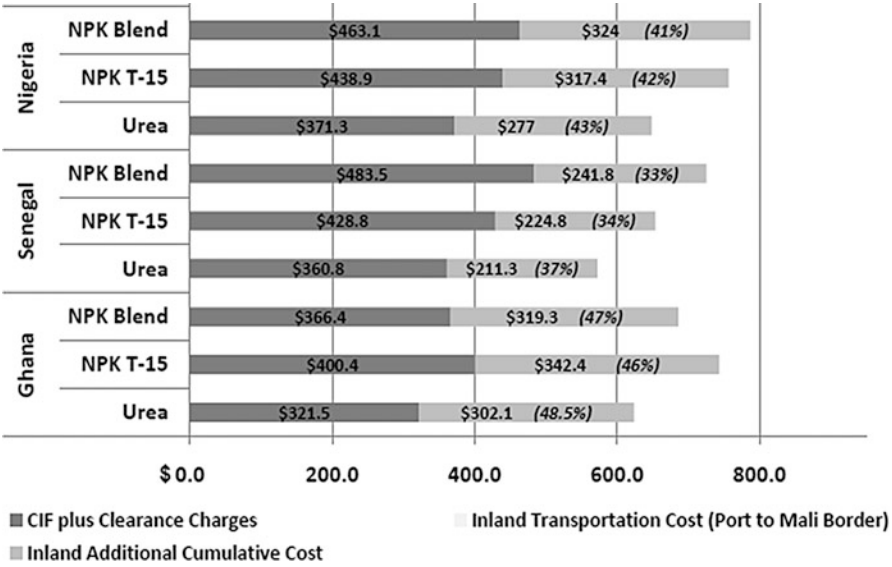

Fig. 14.3 Fertilizer cost structure comparison in 3 West African costal countries

Figure 14.3 also emphasizes that some countries can get better price on international market than others. Therefore, there is need to share information on the best way to plan fertilizer purchase on the international market to provide affordable price to farmers. Some strategies might be shared to help purchase and fret fertilizers at reasonable price.

14.6 Cost Reduction Strategies

14.6.1 Harmonizing Fertilizer Recommendations

As discussed above, cotton fertilizer recommendations really vary from one country to another on some specific elements based on sulfur and boron. Working across agro ecologies can help minimize the differences in fertilizer recommendations and to provide some recommendations that cover many countries. This can enable many countries to order on a large scale and get better price on the international market. Bumb et al. (2011) revealed that this strategy can help gain 8 to 40% of discount on CIF price on the international fertilizer market. The expected profit may be made of formula specificity (30–40%), economy of scale (10–20%), packaging (8–12%), bulk blending (30–35%) and improvement of marketing services (15–20%).

14.6.2 Period of Purchase

Period where fertilizers are ordered is important in price formation. Many buyers from various parts of the world and with different purchase objectives intervene on the fertilizer market. It is useful to know when main suppliers put their bids on the market and to take into account their technical and financial prospects in the negotiations. Many African suppliers arrive late on the market or put their order when big buyers enter in action. It is also advised to avoid going late on the market when the stocks are really low and suppliers are busy for other assignments on the fertilizer value chain.

14.6.3 Volume Ordered, Purchase Modalities and Fret

Many buyers are aware that the quantity of fertilizer ordered at once has significant effect on the price. Moreover, when many cargos are ordered at once, the effect on price reduction is relatively important. To achieve this it is important for West African ports to improve their performance in term of unloading and carrying capacity. It will also be useful that big capacity warehouses are built in entry ports to facilitate fertilizer unloading.

14.6.4 Land Transport

Road harassment which cause incidental expense incurred in fertilizer prices. Fertilizer cost can be reduced by 77USD per ton if road harassment and some useless components of road transport between Accra and Ouagadougou line are reduced (Annequin 2010). These are related to incidental expense removal and competition improvement on transport market currently controlled by national transport unions.

14.6.5 Financial Expenses

Cost of money is very important in fertilizer pricing. Guaranties requested by financial institutions are high in West Africa and can exceed 12% in francophone West Africa and 25% in Ghana. In addition, the financial costs incurred by providers should be considered. Ogling Europe where the cost of money rent is about 5% (Eyes Dupless 2012. Personal communication), mechanisms should be worked out in Africa to lighten these costs.

14.6.6 Taxes and Tariffs

Tariffs and taxes in many countries add significant costs to fertilizer trade. It was, therefore, resolved to eliminate taxes and tariffs on fertilizer and fertilizer raw materials. Wanzala and Groot (2012) notes that Burundi no longer charges value-added tax (VAT) on fertilizers; Cameroon dropped the common external tariff (CET) on fertilizers; and Seychelles removed the import tariff on fertilizers. Although Mali stopped charging VAT on fertilizers, it imposed a withholding tax while Ghana, imposed an administration fee and an Economic Community of West African States (ECOWAS) levy. In Kenya, importers pay an Importer Declaration Fee at the port.

In ECOWAS region, although fertilizer is exempt from the Common External Tariff, some countries still charge an import duty. According to Bumb et al. (2011), Ghana and Mali charge other small levies such as “shipper and council” taxi which add administrative burdens and rent-seeking opportunities that can lead to costly delays in clearing fertilizer shipments at the port

14.7 Organization in the Fertilizer Subsector

In 2012, ECOWAS passed a Fertilizer Regulation (C/REG.13/12/12). This regulation paves a way for a plausible investment policy and regulatory environment conducive to the supply and use of fertilizers in the region. ECOWAS has also established a West Africa Fertilizer Control Committee, which is led by IFDC, to coordinate the implementation of the Fertilizer Regulation in all the 15 Member States. In this respect Mali increased the number of inspectors from 12 to 31.

Ghana, Burkina Faso, Niger and recently Nigeria are implementing fertilizer regulatory mechanism project that will enable each country to improve fertilizer quality

Industry associations have the potential to improve stakeholders' participation in the conduct of interventions linked to their business. More specifically, fertilizer trade group can play an important role in the management and representation of the industry. When well organized, they can influence public policies and promote members' interest and growth. Convinced with stakeholders choice to form fertilizer trade association in West Africa, AFAP is facilitating their organization into fertilizer trade association. The organization can also promote the efficiency of fertilizer use through technology transfer and rapid dissemination of information using their networks.

14.8 Conclusion

The study shows that fertilizer use indicators have been progressing in West Africa but at slow speed. Some recurring constraints linked to fertilizer recommendations are still hampering this process and need to be tacked at regional level instead of country based interventions. Fertilizer supply challenges in the sub-region should be improved by creating an enabling policy environment, improving access to finance, developing regional trade and output markets, and promoting technology transfer through ISFM and other pathways. Real competition among suppliers should be advised to facilitate pricing that makes fertilizer accessible to smallholder farmers.

Some ongoing initiatives such as the startup objective of the Regional Agricultural Development Fund (FRDA) of WAEMU, the ADB Fertilizer Fund and the Regional Support Fund for Agriculture (FRAA) of the ECOWAS need to be promoted. Initiatives such as the West African fertilizer program funded by USAID provides players a guarantee fund for investments in storage capacity and the development of mixing units. AFAP initiatives that facilitate contracts' partnership in agribusiness, offer local, regional and international operators, grants and assistance for loans at attractive conditions to promote investments in the production, storage capacities and distribution of fertilizers in Africa should be supported.

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Chapter 15
Economic Efficiency of Sorghum Microfertilizing in Smallholder Farms in the North-Sudanian Zone of Burkina Faso

A. Traoré, B. Ouattara, H. Sigué, F. Lompo, and Andre Bationo

Abstract The mineral fertilizer microdosing (MD) technique was disseminated in the North-Sudanian zone of Burkina Faso for 3 years, using various extension tools. This study aimed to analyze the economic efficiency as well as farmers' perception of the use of MD technique. Quantitative and qualitative data were collected from 60 demonstration plots conducted by innovative farmers and from 300 households, using an interview guide during the focus groups. The results of the demonstration trials showed that this innovation significantly increased ($P<0.05$) sorghum productivity compared to farmer's practice. It even tripled sorghum yields when combined with soil and water conservation (SWC) techniques, and the use of improved seed varieties. It also led to the efficient use of production capital with cost-benefit ratios ranging from 1.3 to 6.9 depending on the sorghum germplasm and its combined use with SWC techniques. Farmers acknowledged the positive effects of MD technique on their socio-economic well-being through higher incomes from sorghum production and improved food availability. These results challenged policy makers to trigger actions aiming at promoting large-scale adoption of MD technique for sustainable local development.

Keywords Soil fertility • Demonstration trial • Effectiveness • Efficiency • Farmers' perception

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Contents

15.1 Introduction

Continuing soil degradation and soil fertility decline hamper the development of agriculture (Sawadogo 2006), the main economic sector in West African countries (Gafsi and M'Bétid-Bessane 2007). These soils, mainly sandy, and characterized by general nitrogen and phosphorus deficiencies, are subjected to a mining-type of agriculture, which contributes to accelerate the rate of their degradation (Compaoré et al. 2001; Ouattara et al. 2006; Lompo et al. 2007). Moreover, the prevailing climate, especially in the Sahelian part, characterized by strong rainfall variability, hinders the development of farming systems (Paturel et al. 2002; Zoundi et al. 2007; Ouédraogo et al. 2010). In Burkina Faso, to improve production conditions and increase agricultural productivity, the government has been supporting farmers, since the 1980s, in the implementation of soil and water conservation techniques (SWC), and the use of improved seeds varieties, mineral and organic fertilizers (Ouédraogo 2005; Ouédraogo et al. 2010). These different intensification practices have a potential role in restoring degraded land and improving crop yields (Barro et al. 2005; Sawadogo et al. 2008).

However, the use of mineral fertilizers remains low due to financial constraints, climatic and economic risks, lack of appropriate incentive policies, etc. (Tabo et al. 2006; Zoundi et al. 2007). Yet, in the current context of low local availability of organic matter (around 1%) and very low soil fertility levels, it would be difficult to achieve high yields without the use of mineral fertilizers (Ouédraogo 2005; Ouattara et al. 2006). Thus, mineral fertilization through the microdose technique was developed by research in the Sahel to address these economic and edaphic constraints (Palé et al. 2009; Bakayogo et al. 2011). This low cost fertilization consists in applying small amounts of mineral fertilizers into seed holes or after plant emergence. The fertilization rates vary from 2 g for sorghum to 3 g for maize (that to say 62.5–94 kg.ha^{-1}, respectively) (Tabo et al. 2006; Palé et al. 2009). Combined with SWC techniques and organic fertilization, it has optimized crop yields (Zougmoré et al. 2004) in the Sahelian zone. Therefore, its widespread adoption by Burkinabè smallholder farmers could foster food security in the country. With this in view, activities aimed at disseminating the technology of combined use of microdose and SWC techniques with improved varieties of sorghum have been initiated since 2011 by research and development partners through demonstration trials in Burkina Faso. These trials aimed to assess and promote the agronomic and economic potential of the combined use of these technologies.

Several studies have shown the positive agronomic effects of MD technique. However, most authors have either assessed the effects of this innovation alone (Tabo et al. 2006; Aune et al. 2007; Bakayogo et al. 2011) or its application alone on improved seed varieties (Palé et al. 2009). Thus, there is a lack of information on the effects of the combined use of MD with SWC techniques on improved sorghum seed varieties. An analysis of the effects of these combined intensification practices would support the generalization of the results on the importance of MD technique and the promotion of technological options that are economically effective and efficient. Moreover, the analysis of farmers' perceptions of this innovation would reinforce the major conclusions on its effects and would guide not only policy makers in making decisions supporting large-scale dissemination but also researchers in perfecting this innovation. The purpose of this paper is to highlight the agronomic and economic effects of the combined use of MD and SWC techniques on the performance of an improved sorghum germplasm compared to the local variety. It specifically aims to demonstrate whether investment in this technology is economically profitable, technically efficient and socially necessary.

15.2 Materials and Methods

15.2.1 Study Sites

The study was conducted on two sites located at the northern (Zondoma Province) and central (Kourittenga) boundaries of the north Sudanian zone of Burkina Faso.

The province of Zondoma is located between 12° 38′ and 14° 18′ north latitude and 1° 33′ and 2° 55′ west longitude. The area is between isohyetes 600 and 845 mm per year. Soils are poorly developed and can be classified into three main types: (i) undeveloped erosional mineral soils and leached ferruginous soils; (ii) slope and deep valley soils consisting of slightly leached tropical ferruginous soils and hydromorphic soils; (iii) tropical ferruginous soils slightly leached on sand or on birrimian clay (Ganou 2005). Degraded vegetation is composed of tree strata, shrub strata, bushy strata, herbaceous strata and glacis. In general, agro-ecological conditions are precarious.

The province of Kourittenga, lies between 11° 48′ and 12° 34′ north latitude and meridians 0° 20′ and 0° 38′ west longitude. Annual rainfall is between 600 and 900 mm. These soils are shallow and low in fertility. The dominant types are the highly leached ferruginous tropical soils and the low erosional soil resulting from the dismantling of ferruginous crust (48%), vertisols and eutrophic brown soils (25%) and hydromorphic soils (27%). The vegetation is wooded, with the presence of clear forests and gallery forests along permanent or temporary streams. Generally, these soils are low in phosphorus and nitrogen and have degraded structures (Ouattara et al. 2006; Sermé et al. 2015).

Table 15.1 Technology packages implemented

Technologypackages	Factors combined
P1	SWC + MO + MD + IV
P2	SWC + MO + No MD + IV
P3	SWC + MO + MD + LV
P4	SWC + MO + No MD + LV
P5	NoSWC + MO + MD + IV
P6	NoSWC + MO + No MD + IV
P7	NoSWC + MO + MD + LV
P8	NoSWC + MO + No MD + LV

SWC Soil and Water Conservation technique; *NoSWC* Without Soil and Water Conservation technique; *MD* Fertilizer microdosing; *NoMD* Without Fertilizer microdosing; *OM* Organic Matter; *IV* Improved seed Variety; *LV* Local seed Variety

15.2.2 Demonstration Trials

Demonstration trials were carried out from 2011 to 2013 in five villages in the provinces of Zondoma and Kourittenga. Each of thirty farmers (men and women) identified in each province; freely choose a pair of technology packages proposed by the research team. These packages combine SWC and MD techniques, organic matter (OM) input, the use of local seed variety (LV) and/or improved seed variety (IV) of sorghum (Table 15.1). The SWC technique was either stone lines or grass strips; associated with zaï.

Zaï holes were dug during the dry season; with spacing of 0.80 m between sowing lines and 0.40 m between zaï holes on the sowing line; i.e. a density of 31,250 sowing holes per hectare. The zaï holes received uniformly a handful of organic matter (OM) at a rate of about 2.5 tons per hectare.

The amount of fertilizer applied in microdose per zaï hole was 2 g, i.e. 62.5 kg.ha^{-1} of NPK (14-23-14) and 1 g of urea; i.e. 31.2 kg ha^{-1} of urea. NPK and urea were supplied respectively 10 days and 45 days after sowing.

The target crop was either a local seed variety (Kansiagui; Belko; Kapelga) or the improved seed variety (Sariaso 11) of sorghum. Sorghum cropping cycle varied between 75 and 110 days for the local varieties against 90 and 100 days for the improved variety.

The size of the elementary test plot was 500 m^2. The experimental design was the Fisher-type with scattered blocks in which each farmer was considered as a replicate and was testing two technology packages.

15.2.3 Data Collection on Demonstration Plots

Sorghum panicles were collected on the elementary plot, after removing two lines and two edge seed holes on both sides. They were air dried until constant weight. The panicles were then threshed. The grains obtained were weighed.

15.2.4 Analysis of the Economic Efficiency of MD Technique

This analysis highlights the contribution of MD technique to the achievement of households' objectives, which typically, in the African countries, are to meet family food needs through improved yields and increased incomes (Roesch 2007). The indicators used for this analysis were: income or gross margin (*GM*) in CFA francs per hectare and grain yield in kilograms per hectare (*Yield*). To this end, in addition to data relating to grain production on the demonstration plots, input price information was collected from farmers and input suppliers. Yield per hectare and gross margin are obtained by the following formulas:

$$Yield_i = \frac{\mathrm{Pr}\, od_{\mathrm{i}}}{area} \tag{15.1}$$

With i = (1 … 8), the number of treatments; *Prod* is the total production of sorghum in kilograms of an elementary plot, *area* is the area of an elementary plot expressed in hectare.

$$GM_i = Yield_i{}^{*} P_i - TVC_i \tag{15.2}$$

With P_i, the unit price in CFA francs of the kilogram of sorghum; and CVT_i, the total variable costs in CFA francs per hectare of treatment i.

In this paper, MD technique is considered efficient if the yield and gross margin generated by it are significantly higher than on the control. The data used to estimate the various indicators result from 3 years of experimentation in farmers' fields. The descriptive statistics using the SPSS version 20 software produced the average values of the various indicators on the basis of the 3 year data.

15.2.5 Analysis of the Efficiency of Fertilizer Use in Microdose

The relative efficiency of fertilizer use in microdose is measured by productivity in fertilizer value. According to (Gafsi and M'Bétid-Bessane 2007), productivity is a true indicator of the relative technical efficiency of the use of inputs. In terms of value for a given production factor, it corresponds to the increase in the value of the factor, divided by the cost of this factor (Brossier 2007). In the context of this study, the productivity of the MD technique corresponds to the cost/benefit ratio obtained by the ratio between the gross margin of yield increase per hectare due to mineral fertilizers and the cost of these fertilizers. This ratio reflects the gain obtained when the producer invests 1 FCFA in the purchase of mineral fertilizers. This means that labor costs for fertilizer application are not taken into account. The different cost/benefit ratios (CBR) are obtained by the following formula:

$$CBR = \frac{GM_m - GM_t}{TVC_m - TVC_t}$$

Where, GM_m and TVC_m respectively represent the gross margins and the variable costs of the treatments with microdose; GM_t and TVC_t, the gross margin and variable costs of the control treatment.

15.2.6 Analysis of Farmer's Perception of MD Technique

To carry out this analysis, focus group exercises were conducted with 300 farmers. The diagnosis allowed to collect information on the general appreciation of these technologies at the village level. The focus groups were conducted with women and heads of households. This allowed to gather assessments specific to each group. In terms of effects, the focus was on changes in production, income and product availability. Depending on the points of interest, the information collected was summarized in terms of relative frequencies.

15.3 Results

15.3.1 Efficiency of Mineral Fertilizers Microdose Combined with SWC Techniques

The efficiency of mineral fertilizers by microdose in association with SWC techniques was assessed through the evaluation of yields and incomes from the different treatments on the demonstration plots.

Microdose fertilization resulted in significant ($P < 0.05$) increases in sorghum grain yields of 100% and 186% with the local seed variety and the improved seed variety respectively, compared to the control (Fig. 15.1). Its effects are even greater when combined with SWC techniques. This combined use of techniques on the local and improved varieties yielded increases of 158% and 300%, respectively, compared to the absolute control. The yields obtained with the SWC techniques alone were higher than those of the control, but lower compared to those with the microdose alone.

In economic terms, the application of MD technique to sorghum significantly improves the financial situation of farmers (Fig. 15.2). This generates incomes of 100, 385 and 184, 625 CFAF.ha^{-1} respectively with local and improved seeds of sorghum varieties, resulting in increases of 57% and 160%. These effects are further enhanced when combined with SWC techniques: income increases by 118% with the local variety and 284% with the improved variety.

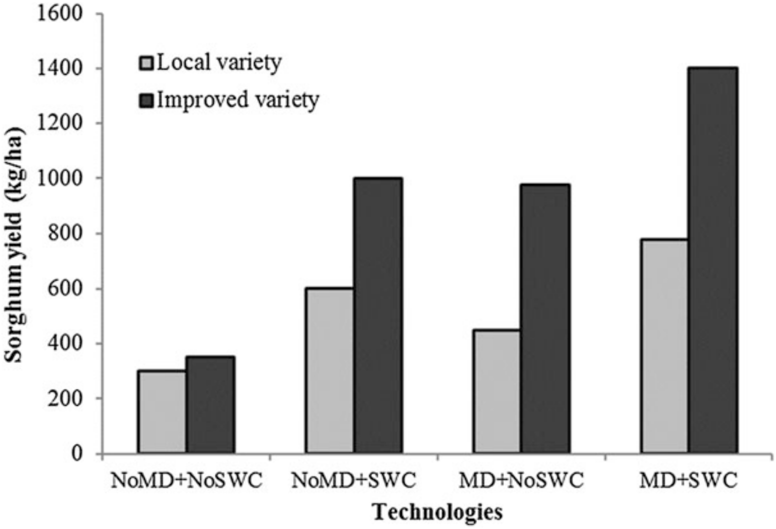

Fig. 15.1 Response of sorghum to MD combined with SWC techniques. NoMD + NoSWC = without Microdose and without SWC techniques; NoMD + SWC = without Microdose with SWC techniques; MD + NoSWC = Microdose without SWC techniques; MD + SWC = Microdose with SWC techniques

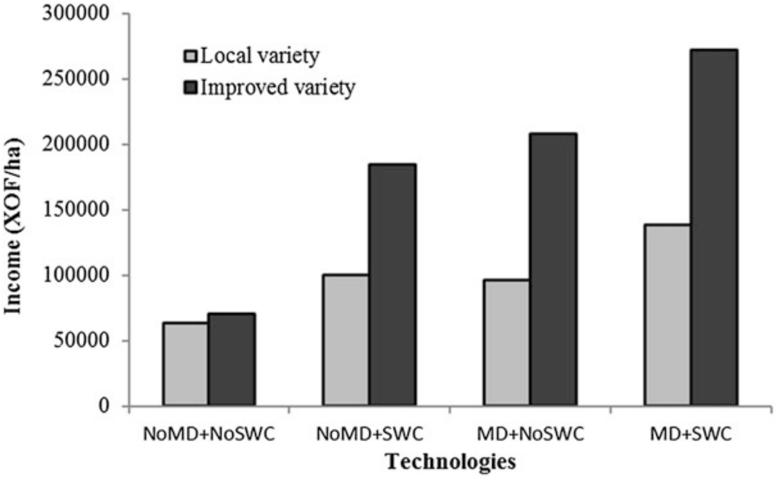

Fig. 15.2 Effect of fertilizer microdosing on income from sorghum crop. NoMD + NoSWC = without Microdose and without SWC techniques; NoMD + SWC = without Microdose with SWC techniques; MD + NoSWC = Microdose without SWC techniques; MD + SWC = Microdose with SWC techniques

15.3.2 Analysis of Mineral Fertilizer Microdosing Technique Efficiency

Mineral fertilization by microdose has made profitable farmers' investments in mineral fertilizers. Indeed, for 1 CFAF invested in the purchase of mineral fertilizer in microdose, the farmer had a profit of CFAF 1.6 when growing the local seed variety and 3.8 CFAF when growing the improved seed variety of sorghum. When combined with SWC techniques, microdose further increased capital productivity with respective profits of 2.6 and 6.9 CFAF for local seed variety and the improved seed variety for each Franc invested.

According to more than half of the farmers who participated in discussions within the focus groups, MD technique has induced considerable change in sorghum intensification practice in the study areas. It has increased the number of users of mineral fertilizers by reducing the level of risk associated with investment in fertilizers. Farmers believe that, with small doses, they incur very few financial risks besides the fact that climatic risks are also reduced by the SWC techniques combined with microdose. They also mentioned that this fertilization technique is much more applied on sorghum and cowpea, which are the major crops respectively for heads of households and women of the study sites.

The results of the focus groups also showed that farmers are convinced of the positive effects of microdose on yields. Indeed, 80% of those who adopted this innovation, carried out demonstration trials, or participated in guided visits reported that in plots where yields did not exceed 300 kg/ha, microdose fertilization enabled to achieve more than 700 kg and more than 1000 kg/ha when combined with SWC techniques. According to them, this yield increase helped to improve the food situation in households and increase the quantities of cereals stored in warrantage warehouses. Moreover, they stressed that this innovation has improved the availability of fodder for animals, all things favorable to the development of agro-pastoralism.

As for the economic aspect, on the whole, farmers are convinced of the economic impact of the MD technique. According to its adopters, this type of fertilization helped to improve their financial situation directly and indirectly. Directly through increased production which generates higher incomes and indirectly through greater food availability of food to the extent that the money intended for the purchase of food supplement is saved. According to women producing cowpea, increased income generated through MD technique has enabled most of them to carry out secondary activities, including trade, which also provides additional incomes.

15.4 Discussion

The results of the study show that microdose is a technique economically effective and efficient. This can be explained by the low production costs due to the use of low fertilizers rates, and its high agronomic potential. This fertilization practice has improved mineral fertilizer use efficiency by limiting losses through leaching and reducing competitiveness between weeds and crops. This generates higher yields which, coupled with low production costs, makes investment in mineral fertilizers more profitable for farmers. (Bationo et al. 1998) held the view that nutrient storage in the proximity of the plant root system through microdose ensures more efficient use and therefore proper plant growth and higher yields.

These results are consistent with those of Aune et al. (2007) on sorghum and millet, of (Hayashi et al. 2007) on millet, of (Tabo et al. 2007; Bakayogo et al. 2011) on sorghum, millet and maize) in different countries of West Africa. Farmers of the study sites are well convinced of the positive effects of MD technique on their socio-economic indicators. These results are in line with those obtained in a study on farmers' perception of SWC techniques in northern Burkina Faso (Ouédraogo et al. 2010). Since meeting food needs and securing a minimum income to cover family spending priorities are considered to be the priority objectives of African farmers (Roesch 2007), farmers' positive perception of the microdose effects on these vital issues should facilitate its widespread adoption.

Moreover, the combination of MD with SWC techniques further increases its agronomic potential. This result confirms those of (Zougomré et al. 2000; Zougmoré et al. 2003a, b, 2004; Sawadogo et al. 2008) indicating that the efficiency of soil fertility management techniques depends on their combination. These authors found in various agroclimatic zones of Burkina Faso that the combination of SWC techniques with organo-mineral fertilization optimized crop yields compared to individual techniques. SWC techniques, thanks to soil moisture retention by the slowdown in water speed and rainwater harvesting, enable optimal use of mineral fertilizers by the crops (Barro et al. 2005; Sawadogo et al. 2008). These techniques limit losses of organic and mineral fertilizers by runoff waters and reduce the degradation of soil surface layer. As a result, microdose combined with SWC improves both the structure and the chemical parameters of the soil.

Moreover, the effects of microdose are enhanced with the use of improved seed varieties due to their very high agronomic potential which allowed obtaining productions even on marginal lands. The effects of microdose on improved varieties are considerably greater than on local varieties. This result is consistent with the theory relating to the important role of improved seed varieties in increasing the agronomic and economic efficiency of MD technique as shown by the studies of (Palé et al. 2009, Twomlow et al. 2010). The positive effects of microdose combined with SWC techniques and improved seed varieties on yields and incomes support the agronomic and economic potential of the combination of the three technological options. The combination of microdose with SWC techniques on improved varieties leads to highest yields and incomes, which ensures better profitability from fertilizer investments.

In light of this discussion, combining fertilization technologies is a good strategy to significantly increase crop yields while protecting the environment in the arid and semi-arid areas of the Sahel.

15.5 Conclusion

This study has shown that mineral fertilizer microdosing (MD) technique is economically efficient and socially necessary. Combined with soil and water conservation (SWC) techniques on improved seed varieties, it has significantly increased sorghum yields and consequently food availability and farmers' incomes in the study areas. Analysis of farmers' perception of the microdose technology indicates that they clearly perceive the beneficial effects of this innovation through improved yields, higher incomes, food availability in households and positive change in their production system.

Thus, promoting a massive adoption of MD combined with SWC techniques for the cultivation of improved seed varieties of sorghum would be a good alternative for sustainable soil management. This innovation should enable to substantially improve food security and farmers' incomes while breaking the vicious circle of rural poverty in West Africa.

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Chapter 16
Improving Fertilizer Recommendations for Cocoa in Ghana Based on Inherent Soil Fertility Characteristics

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Abstract In Ghana, cocoa has traditionally been grown as a low input crop, which has caused soil fertility deterioration, and thus, the need to integrate fertilizer use into cocoa agricultural practices. However, fertilizers recommended to farmers are general in nature and do not account for specific crop needs and inherent soil fertility conditions. This study evaluates the use of a soil diagnosis model to determine fertilizer recommendations for cocoa based on inherent soil fertility characteristics in the cocoa growing zones of Ghana. The site-specific fertilizer formulations were tested against blanket recommendations (Asaase Wura and Cocofeed) in farmers' settings from 2009 to 2011. The results showed that DS-formulated site-specific fertilizer performed better than all blanket fertilizers in Western soils especially on the Ferralsols which are very acidic and depleted of base cations. On the other soil conditions, the site-specific formulations were comparable to the blanket formulations. Trend analysis of cocoa response to applied fertilizer suggests that P is a major determinant of cocoa productivity and that P2O5 rates >120 kg ha^{-1} would be required, when justified economically, for optimal cocoa yield, while potassium could be kept at around 45 kg K_2O ha^{-1}.

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In view of these results, the cocoa fertilizer formulas proposed for western regions of Ghana could be revised according to the DS model recommendations by taking into consideration the optima presented above. For the other cocoa regions, the DS would not be economic and therefore, proposed formulas should keep P_2O_5 and K_2O around the optima above-presented while compensating for nutrients exported by the crop.

Contents

16.1 Introduction

Ghana is the second largest cocoa producer in Africa with an annual production of >700,000 tons. The traditional cropping system is a low input system with little or no application of fertilizer, which results in the long run in depleted soil fertility and reduced crop yield. Increase in cocoa production in Ghana has been achieved mostly through expansion and encroachment upon the remnant forest, particularly in the Western region where soils are said to be unsuitable for cocoa production (Appiah et al. 2000). This encroachment on forest reserves would be spared or greatly reduced, and acceptable or better cocoa yield would be achieved if cocoa cultivation is intensified through adoption of good agronomic practices including judicious application of fertilizer (Gockowski and Sonwa 2010).

Recent introduction of fertilizer into cocoa cultivation practices in Ghana (Appiah et al. 2000) aims at maintaining soil fertility and sustaining crop productivity. However, the fertilizer proposed to cocoa farmers in Ghana is of a blanket formulation with a rate of application of approximately 150 kg acre^{-1} regardless of soil type and agroecological conditions (CRIG 2008). Although application of these blanket fertilizer formulas results in yield increase (Appiah et al. 2000), it is not supportive of sustainable cocoa production because it fails to account for the inherent characteristics of the soils on which cocoa is grown in the various agroecozones in Ghana. Moreover, research results on cocoa nutrition in West Africa suggest the need for balanced ratio between nutrients, especially N and P on the one hand, and K, Ca and Mg on the other hand, to optimize cocoa productivity (Jadin and Snoeck 1985; Snoeck et al. 2006).

Cocoa soils in Ghana fall broadly in three suitability categories (Anim-Kwapong and Frimpong 2006):

- The unsuitable cocoa soils, which are highly desaturated, corresponding to the Ferralsols and overlying Acrisols in Western region.
- The suitable cocoa soils, moderately desaturated, corresponding to the Acrisols and Lixisols in the FAO classification.
- The highly suitable cocoa soils are slightly desaturated equivalent to the Acrisols-Nitisols in the FAO classification.

Our recent survey of soil fertility status in the cocoa regions of Ghana (Dossa et al. 2016, unpublished manuscript) showed that most Ghanaian cocoa soils have sub-optimal chemical properties and therefore, sustainable cocoa production on these soils would require sound fertilizer recommendations.

The objectives of this fertilizer recommendation exercise was (1) to formulate balanced fertilizer formulas for cocoa based on soil characteristics and (2) test the effectiveness of the new fertilizer recommendations in farmers' settings.

16.2 Materials and Methods

Based on inherent soil fertility diagnosis carried out in the cocoa zones of Ghana in 2009, site-specific fertilizers were formulated for the major soil groups and ecologies using the "Diagnostic-sol" (DS) software (Jadin and Snoeck 1985). This tool was recently adapted to Ghanaian conditions (Snoeck et al. 2006).

16.2.1 Model Presentation and Operational Procedure

The DS is a computer program developed to formulate fertilizer rate for optimal cocoa production (Jadin and Snoeck 1985). Optimal levels of nutrient accounted for in the model are:

- Soil extractable P ($NH_4F + NaHCO_3$) = 100 ppm
- N tot/P_2O_5tot < 2
- [Exchangeable bases (cmol kg^{-1}) + 6.15]/Ntot‰ = 8.9
- Proportion of bases as 8%K, 68%Ca and 24%Mg
- Minimum base saturation of 60%

The model compares actual values of nutrients in soil with optimal values and computes amounts of major nutrients required to correct any imbalance. In addition, fertilizer corresponding to nutrient export through harvest of cocoa beans is taken into consideration in order to make a final fertilizer recommendation. Using the DS tool, mean site-specific fertilizer formulas computed for the different agroecologies are as shown in Table 16.1.

Table 16.1 Nutrient contents in the DS balanced site-specific fertilizer formulas at plot level (T6) and using mean regional soil characteristics (T7)

		N	P_2O_5	K_2O	MgO	CaO
Regional soil units						
Western Acrisols	T6	7	105	70	14	250
	T7	7	135	50	19	333
Western Ferralsols	T6	14	120	40	34	333
	T7	14	150	20	24	416
Brong Ah Nitisols	T6	42	90	110	34	50
	T7	35	97.5	160	87	33
Ashanti Acrisols	T6	28	90	190	43	166
	T7	28	90	200	96	133
Central Lixisols	T6	35	105	90	24	83
	T7	35	105	120	10	83

16.2.2 Validation of Proposed Site-Specific Fertilizer Formulas

The validation of the site-specific fertilizer formulations was conducted from 2009 to 2011 in farmers' settings.

16.2.2.1 Study Area and Site Selection

The study was conducted in the semi deciduous forest and rain forest agroecological zones of Ghana located 3°12′W and 0°37′E latitudes and 4°54′N and7°10′N longitudes. The climate is a Sudan Guinean type characterized by weak temperature amplitudes (26–30 °C), high relative humidity (80–90%) and a bimodal rainfall regime distributed from March–July (main season) to September–November (minor season), with mean annual rainfall of 1500 mm in the deciduous forest zone, and 2200 mm in the rain forest zone. The soils are highly weathered and comprise the Acrisols, Lixisols, Nitisols and Ferralsols soil units of the FAO soil classification (ISRIC 2006).

Sites for the fertilizer experimentation were selected to span the major soil units and hydrological regimes prevailing in the cocoa zones of Ghana. Selected plantations were healthy mature cocoa plantations >3.5 acres with light or no shade. As much as possible, the plots were located near a road infrastructure to serve as a demonstration plot to non-participating farmers. Plots were of flat topography or on a gentle slope. The geographical distribution of plots involved in the validation process is shown in Table 16.2.

Table 16.2 Communities involved in plot selection for validation of site-specific fertilizer formulas

Region	Community	Soil group	Number of replicates
Ashanti	Agona	Acrisols	2
Ashanti	Konongo	Acrisols	2
Brong Ahafo	Bechem	Nitisols	2
Brong Ahafo	Kenyase	Nitisols	2
Central	Assin Fosu	Lixisols	2
Western	Dunkwa	Acrisols	1
Western	Aboso	Acrisols	1
Western	Elubo	Ferralsols	2
Western	Sefwi Wiaso	Acrisols	2

16.2.2.2 Experimental Design and Treatment Application

Because of presumed micronutrient limitation to optimal cocoa productivity (Asomaning and Kwakwa 1967; Ahenkorah 1969; Dossa et al. 2016, unpublished manuscript), a set of micronutrients consisting of a compound EDTA-chelated trace elements containing 0.28% Cu, 7.5% Fe, 3.5% Mn, 0.65% B, 0.3% Mo and 0.7% Zn was added to the main fertilizer treatments and applied as foliar application at a rate of 0.5 kg per hectare 3 times during the growing season.

Treatments were arranged in a split plot design with the chelated micronutrients as the main plot factor and the combination of major nutrient treatments including the site-specific fertilizer formulations as the subplot factor. The subplot fertilizer treatments were:

T1 = Control without fertilizer
T2 = Control blanket fertilizer Asaase Wura (81 kg P_2O_5, 67 kg K_2O, 21 kg MgO, 33 kg CaO per hectare)
T3 = Control blanket fertilizer Cocofeed (111 kg P_2O_5, 74 kg K_2O per hectare)
T4 = Asaase Wura + (62.5 kg P_2O_5) + 20 kg ha^{-1} N
T5 = Asaase Wura + (62.5 kg P_2O_5) + 40 kg ha^{-1} N
T6 = Plot-specific DS formula (see details in Table 16.1)
T7 = Mean DS formula based on mean regional soil characteristics (see details in Table 16.1)

Treatments T4 and T5 were included to account for the P sorption capacity of the soils and to evaluate the beneficial effect of N addition.

The experimental unit was a 20 m × 15 m plot with a 2 m guard between two adjacent plots. Fertilizer was uniformly broadcast all over the 300 m^2 plot. The broadcasting method was adopted because the cocoa trees were most of the time not planted in rows, resulting in higher densities than the recommended one (1111 trees ha^{-1}). Nitrogen in the formula was applied in two splits at 30 day interval. In composing the site-specific fertilizer formulas, the following simple fertilizers were used to supply the various nutrients; triple superphosphate (TSP), muriate of potash

(MOP), kieserite ($MgSO_4$), ammonium sulfate ($(NH_4)_2SO_4$) and hydrated lime Ca $(OH)_2$.

Application of fertilizer started in September in 2009 and in May–June for subsequent years until 2011.

16.2.2.3 Data Collection and Processing

Mature pods were periodically harvested (fortnightly or when needed), sorted into healthy, diseased (black pod), immature ripe pods and malformed or rodent damaged pods. This last category forms a small portion of the total pods and, therefore, is not considered in this report. Pod number was taken according to treatment design, and the potential yield was estimated based on a conversion factor of 0.33 g dry beans per pod.

16.2.2.4 Statistical Analysis

Statistical analysis of the data was performed using PROC MIXED subroutine (SAS Institute 1999) for a split-plot design. Cocoa yield in 2010 and 2011 was treated as repeated measures in time and analyzed as a split-split-plot design, with year as a whole plot factor. In analyzing the data, initial pod count was treated as a covariate. Subsequently, because of insignificant main plot factor effect, the subplots were treated as blocks and the data analyzed as a randomized block design using PROC GLM (SAS Institute 1999). The data was examined within soil units but was also pooled to get the overall fertilizer effect averaged over soil units and agroecological regions.

16.3 Results and Discussion

16.3.1 Major Fertilizer and Micronutrients Effect on Cocoa Yield

The effect of micronutrient application was similar in 2009 (minor harvest) and 2010. To illustrate this, results of the 2010 data are shown in Table 16.3. Micronutrients supplied as foliar application did not significantly affect cocoa yield (1063 kg ha^{-1} with foliar application of micronutrients versus 1000 kg ha^{-1} for plots not receiving micronutrients, mean data averaged across soil units).There was a significant major fertilizer treatment effect within the Acrisols and Ferralsols in Western region. The control without fertilizer had the lowest yield. It's worth noting that site-specific formulated fertilizer treatments had the highest yield, although not statistically different from the other fertilizer treatments. Soil unit

Table 16.3 Fertilizer effect on cocoa yield (kg ha^{-1}) and percentage of yield affected by black pod disease within major soil units

Treatments	Acrisols Ashanti	Acrisols Western	Ferralsols Western	Nitisols Brong Ahafo	Lixisols Central
Foliar micronutrients					
With	866	849	1385	817	1398
Without	733	862	1182	875	1350
Probability	NS	NS	NS	NS	NS
Major treatments					
T1 (control no fertilizer)	632	607c[a]	856c	702	990
T2 (Asaase Wura)	696	957ab	1130bc	815	1399
T3 (Cocofeed)	892	824b	1332a	838	1348
T4 (Asaase Wura + P + 20 kg N ha^{-1})	796	755b	1158b	809	1661
T5 (Asaase Wura + P + 40 kg N ha^{-1})	820	856b	1371a	1020	1473
T6 (Plot-specific DS)	801	1094a	1557a	821	1455
T7 (Mean regional DS)	958	894ab	1581a	917	1295
Mean	**799**	**855**	**1283**	**846**	**1374**
Probability	*NS*	*$P < 0.05$*	*$P < 0.05$*	*NS*	*NS*

[a] Means in a column followed by the same letter are not statistically different at $P < 0.05$

by region differed in their mean potential cocoa yield, with Lixisols in Central region (1374 kg ha^{-1}) ranking first followed by Ferralsols in Western region (1283 kg ha^{-1}) while the other soil units showed the lowest yield.

16.3.2 *Effect of Main Fertilizer Treatments on Cocoa Within the Acrisols*

16.3.2.1 Acrisols in Western Region

Statistical analysis of yield data for 2010 and 2011 seasons showed that all fertilizer treatments induced higher cocoa yield relative to the control with no fertilizer application ($P < 0.05$) (Table 16.4). The average yearly marginal yield as a result of fertilizer application was 429 kg ha^{-1}. The plot-specific DS formula had the highest yield in both 2010 and 2011 agricultural seasons (1229 and 1213 kg ha^{-1} respectively). There was no fertilizer treatment effect on cocoa black pod incidence. Cumulative yield (2010–2011 seasons) showed basically the same trend reported for the 2011 data with yield of 2442 kg ha^{-1} for the plot-specific DS and 1353 kg ha^{-1} with the control without fertilizer application. The blanket formulations were statistically comparable to the site-specific DS formulations.

Table 16.4 Effect of various fertilizer treatments on cocoa yield (kg ha^{-1}) and black pod disease incidence within the Acrisols in Western region

Treatments	2010		2011		Yield 2010–2011 (kg ha^{-1})
	Yield (kg ha^{-1})	% black pod	Yield (kg ha^{-1})	% black pod	
T1 (control no fertilizer)	720c[a]	6.3	633c	3.8	1353c
T2 (Asaase Wura)	1190a	6.7	1086ab	4.3	2276a
T3 (Cocofeed)	1153a	5.6	1096ab	3.5	2249a
T4 (Asaase Wura + P + 20 kg N ha^{-1})	948b	8.9	1063ab	3.4	2011b
T5 (Asaase Wura + P + 40 kg N ha^{-1})	1132ab	5.6	959b	3.1	2091b
T6 (plot-specific DS)	1229a	5.9	1213a	2.9	2442a
T7 (mean regional DS)	1093ab	4.8	1100ab	3.2	2193ab
Probability	$P < 0.05$	*NS*	$P < 0.001$	*NS*	$P < 0.001$

[a] Means in a column followed by the same letter are not statistically different at $P < 0.05$

Table 16.5 Effect of various fertilizer treatments on cocoa yield (kg ha^{-1}) and black pod disease incidence within the Acrisols in Ashanti region

Treatments	2010		2011		Yield 2010–2011 (kg ha^{-1})
	Yield (kg ha^{-1})	% black pod	Yield (kg ha^{-1})	% black pod	
T1 (control no fertilizer)	587c[a]	3.8	506c	0.27	1093c
T2 (Asaase Wura)	863a	3.3	868a	0	1731a
T3 (Cocofeed)	780ab	4.3	700b	0	1480b
T4 (Asaase Wura + P + 20 kg N ha^{-1})	718b	3.9	828a	0	1546b
T5 (Asaase Wura + P + 40 kg N ha^{-1})	823ab	4.1	887a	0.16	1710a
T6 (plot-specific DS)	767b	4.0	869a	0	1636ab
T7 (mean regional DS)	890a	4.6	810a	0	1700a
Probability	$P < 0.05$	*NS*	$P < 0.05$	*NS*	$P < 0.01$

[a] Means in a column followed by the same letter are not statistically different at $P < 0.05$

16.3.2.2 Acrisols in Ashanti Region

Within this soil unit, all fertilizer treatments performed equally well and were superior to the control without fertilizer ($P < 0.05$). There was no difference between the DS formulas and the blanket Asaase Wura (T2) or Cocofeed (T3) (Table 16.5). Cumulative yield analysis showed that the best treatments were T2 (1731 kg ha^{-1}), T5 (1710 kg ha^{-1}), T7 (1700 kg ha^{-1}) and T6 (1636 kg ha^{-1}). There was no fertilizer treatment on cocoa black pod disease incidence.

Table 16.6 Effect of various fertilizer treatments on cocoa yield (kg ha^{-1}) and black pod disease incidence within the Ferralsols in Western region

Treatments	2010		2011		Cumulative yield 2010–2011 (kg ha^{-1})
	Yield (kg ha^{-1})	% black pod	Yield (kg ha^{-1})	% black pod	
T1 (control no fertilizer)	836e*	7.8	494d	8.0	1330e
T2 (Asaase Wura)	1123d	7.0	665c	3.0	1788d
T3 (Cocofeed)	1622b	7.6	1070a	7.8	2692b
T4 (Asaase Wura + P + 20 kg N ha^{-1})	1307 cd	7.2	779bc	6.3	2086 cd
T5 (Asaase Wura + P + 40 kg N ha^{-1})	1350c	8.4	851b	7.1	2201c
T6 (Plot-specific DS)	1851a	6.9	1183a	4.0	3034a
T7 (Mean regional DS)	1815a	6.3	1025ab	6.6	2840ab
Probability	$P < 0.05$	*NS*	$P < 0.1$	*NS*	$P < 0.1$

*Means in a column followed by the same letter are not statistically different at $P < 0.05$

16.3.3 Effect of Fertilizer on Cocoa Within the Ferralsols in Western Region

Within the Ferralsols soil unit and for the 2010 season, the DS formulated recommendations (T6 and T7) yielded statistically higher than the other fertilizer treatments ($P < 0.05$) (Table 16.6). In 2011, a similar trend was observed, but the magnitude of the differences was lower and only the plot-specific DS formulated balanced fertilizer (T6) showed statistically higher yield than the other treatments. Overall, application of fertilizer induced a yield increase relative to the control without fertilizer. There was no fertilizer effect on cocoa black pod incidence. Cumulative yield for 2010–2011 was highest with the DS formulations (2840 and 3034 kg ha^{-1} for T7 and T6 respectively) compared with 1788 kg ha^{-1} with T2, 2692 kg ha^{-1} with T3 and 1330 kg ha $^{-1}$ with the control without fertilizer. It should be noted that treatments with N produced higher yields than the Asaase Wura control (T2) and undermines the idea that addition of N to cocoa fertilizer depresses yield (Ahenkorah and Akrofi 1975). Observed depressive effect of N commonly reported (Ahenkorah and Akrofi 1975) owes to the fact that, in P deficient soil conditions, addition of N induces biomass growth which results in an ultimately greater P deficiency because of the biomass P dilution.

The results on the Ferralsols are consistent with conclusions of a previous fertilizer recommendation study for cocoa in Ghana (Snoeck et al. 2010).

Table 16.7 Effect of various fertilizer treatments on cocoa yield (kg ha^{-1}) and black pod disease incidence within the Nitisols in Brong Ahafo region

Treatments	2010		2011		Yield 2010–2011 (kg ha^{-1})
	Yield (kg ha^{-1})	% black pod	Yield (kg ha^{-1})	% black pod	
T1 (control no fertilizer)	908	12.6	515	6.6	1423
T2 (Asaase Wura)	1091	11.2	614	8.9	1705
T3 (Cocofeed)	1046	12.7	543	3.6	1589
T4 (Asaase Wura + P + 20 kg N ha^{-1})	1109	12.5	670	5.7	1779
T5 (Asaase Wura + P + 40 kg N ha^{-1})	1255	15.6	580	7.8	1835
T6 (Plot-specific DS)	990	18.2	596	8.3	1586
T7 (Mean regional DS)	1055	18.6	507	12.8	1562
Probability	*NS*	*NS*	*NS*	*NS*	*NS*

16.3.4 Effect of Fertilizer on Cocoa Within the Nitisols in Brong Ahafo Region

Within this soil unit, there was no significant difference between fertilizer treatments. In general, application of fertilizer resulted in yield increase, but the mean marginal yield increase was only small (183 kg in 2010 and 70 kg in 2011) (Table 16.7). There was a trend of treatments including N (T4 and T5) yielding higher than the DS formulated fertilizers, which could be attributed to the better P availability in these soils.

The non significant effect of fertilizer effect within this soil unit may be ascribed to its relatively high inherent nutrient status as shown in our soil fertility assessment report (Dossa et al. 2016, unpublished manuscript), and probably some unresolved nutrient imbalance.

16.3.5 Effect of Fertilizer on Cocoa Within the Lixisols in Central Region

In this soil conditions, the DS formulas did not perform better than the other treatments (Table 16.8). There was a trend of treatments T4 and T5 (Blanket Asaase Wura reinforced with P and supplemented with N) performing slightly better than the other treatments. As within the other soil units, there was no fertilizer treatment effect on cocoa black pod incidence.

Table 16.8 Effect of various fertilizer treatments on cocoa yield (kg ha^{-1}) and black pod disease incidence within the Lixisols in Central region

	2010		2011		
Treatments	Yield (kg ha^{-1})	% black pod	Yield (kg ha^{-1})	% black pod	Yield 2010–2011 (kg ha^{-1})
T1 (control no fertilizer)	1081	6.8	939	16.0	2020
T2 (Asaase Wura)	1330	5.5	1549	10.8	2879
T3 (Cocofeed)	1366	4.5	1433	10.0	2799
T4 (Asaase Wura + P + 20 kg N ha^{-1})	1723	8.7	1791	11.2	3514
T5 (Asaase Wura + P + 40 kg N ha^{-1})	1526	5.7	1545	11.9	3071
T6 (Plot-specific DS)	1415	6.3	1480	12.2	2895
T7 (Mean regional DS)	1240	5.9	1346	12.0	2586
Probability	*NS*	*NS*	*NS*	*NS*	*NS*

16.3.5.1 Average Effects of Fertilizer Treatments

When all yield data were pooled to get an overall fertilizer effect averaged over soil units and regions, there was no significant difference between the DS balanced fertilizer formulations and the other fertilizer treatments. It should be noted that the DS balanced formulas performed well in very acidic and highly leached conditions such as those exhibited by the Ferralsols. In such conditions, water availability is near optimal with relatively short dry spells. Such conditions favor expression of fertilizer effect. Assessing the overall effect of fertilizer by regressing crop response against applied nutrients, it appeared that phosphate is a major element controlling cocoa yield as illustrated by the linear fit ($R^2 = 0.79$) of crop response over P fertilizer rates (Fig. 16.1). This suggests that P_2O_5 rates over 120 kg ha^{-1} would induce a significant crop response throughout the cocoa zones in Ghana. On the other hand, potassium exhibited a quadratic fit with eq. $Y = 58.31x – 0.655x^2 + 1374$ ($R^2 = 0.97$). Solving the derivative of this equation for zero results in an optimum potassium rate of about 45 kg K_2O ha^{-1}. Most of the fertilizer formulas used for cocoa in Ghana have potassium rates higher than this value, an indication of luxurious fertilization with regard to potassium.

16.4 Conclusions and Perspectives

Results of fertilizer treatment showed significant and variable treatment effects. In the western cocoa region of Ghana, especially within the Ferralsols where soils are acidic (mean $pH < 5.5$) and depleted of base cations, the site-specific DS formulas performed well and were superior to the blanket recommendations. Mean marginal yield obtained with the DS formula was 623 kg ha^{-1} against the Asaase Wura

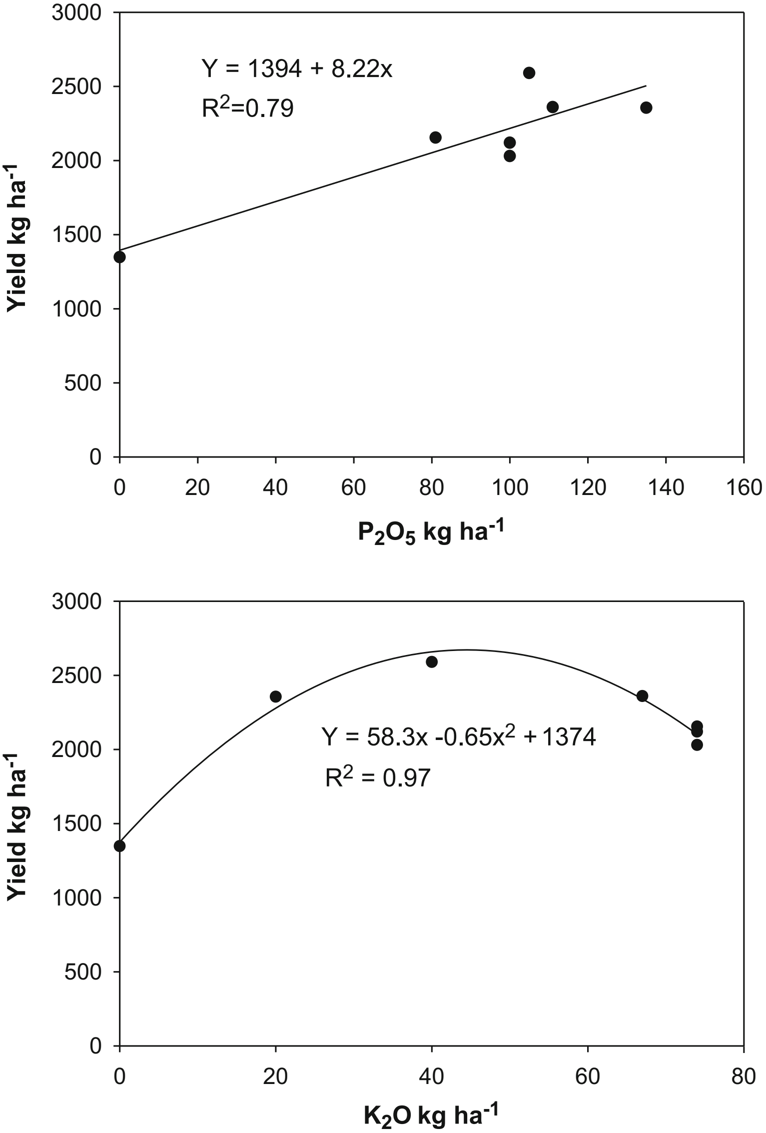

Fig. 16.1 Trend analysis of cocoa response to added phosphorus and potassium fertilizers

representing a 35% increase in cocoa yield. In regions other than the Western region and on the other soil units, the site specific fertilizer formulations were not statistically superior to the blanket fertilizer recommendations. However, trend analysis of cocoa response to applied fertilizer showed a linear fit for phosphate and a quadratic fit for potassium. These results suggest that, depending on the cocoa price and socio economic conditions of the farmer, P in fertilizer formulas could be upgraded to >120 kg ha^{-1} while potassium should be kept at ~50 kg K_2O ha^{-1}. In view of these results, it is suggested that the fertilizer formulas proposed for western regions of Ghana where soil conditions are similar to that of the Ferralsols, be revised according to the DS model taking into consideration the optima presented above. For the other cocoa regions, the DS would not be economic and therefore, proposed formulas should keep P_2O_5 and K_2O around the optima above-presented while compensating for nutrients exported by the crop. Although not shown in this study, inclusion of trace elements such as Zn, B and Mo in the balanced fertilizer formulations should be considered because, from our initial soil fertility assessment and other studies (Ahenkorah 1969; Asomaning and Kwakwa 1967), these elements are likely to limit cocoa productivity, particularly that of high yielding cocoa hybrids in Ghanaian ecosystems.

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Chapter 17
A Review of Study on Fertilizer Response by the Oil Palm (*Elaeis guineensis*) in Nigeria

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Abstract Oil palm constitutes important components in meeting both domestic and industrial requirement of the Nigerian economy due to its high oil yield per hectare per year. The need for research into soil and nutrient requirements of oil palm was as result of nutrient deficiency symptoms; poor growth and declining yields manifested by the crop in condition of low soil fertility and nutrient imbalance, hence the need for fertilizer application for good yield to be obtained. This study was conducted by reviewing the soil nutrient balance and fertilizer use research conducted at the Nigerian Institute for Oil Palm Research and works of other researchers. It also includes studies conducted on the use of locally sourced rock mineral fertilizers. Results of these old fertilizer trials emphasized the need for soil and site specificity in their fertilizer requirements. The studies revealed that one or more of the elements N, P, K, and Mg are usually in high demand for optimum yield. In the light of the aforementioned, the following were recommended; there is need to ensure adequate supply and quality certification of fertilizers used for the various trials; the studies on oil palm response to fertilizers in Nigeria should be extended to the other parts of the country which is perceived to be marginal in terms of soil and climatic conditions for oil palm cultivation; following recent changes in climatic conditions, there is need to re-establish the earlier trials which gave rise to the present fertilizer recommendation for oil palm cultivation.

Keywords Fertilizer • Response • Oil Palm • Nigeria

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Contents

17.1 Introduction

17.1.1 Climate and Soil Condition for Oil Palm Cultivation

Climate and soil constitutes the major aspects of the environment that greatly determine the yield of any crop. Oil palm cultivation in Nigeria is predominant in the southern belt which lies in the rain forest zone with an annual precipitation of about 1889–2560 mm. The region is characterized by an uneven annual rainfall distribution with a 3–5 month period of water deficit usually between November and March. During this period the soil is usually too dry to support palms at potential evapor-transpiration rate (Omoti et al. 1987). The requirement for solar radiation cannot be known exactly but however, the general conclusions according to Hartley (1988) are as follows;

Sunshine of 5–7 h/day in all months
Solar radiation of 15 MJ/m^2 per day.
Mean maximum temperature of about 29–33 °C
Mean minimum temperature of 22–24 °C with relative humidity of about 85% (Figs. 17.1, 17.2 and 17.3).

The major soils of the oil palm belt in Nigeria are the *Acid Sands, the Basement Complex soils and the alluvial soils* of marine and river origin occurring in the Niger Delta and other wetland of southern Nigeria (Omoti et al. 1987). The distribution, geomorphology, and classification of these soils are well documented in literatures (Tinker and Ziboh 1959; Ataga et al. 1981). The Acid Sands which constitute the most widely cultivated soils to oil palm are deep, free draining and largely stone free but have the disadvantage of been excessively sandy in texture and low in exchangeable bases especially potassium. (Benin Fasc) and potassium and Magnesium (Calabar Fasc). The total reserve of the cation and phosphorus are also low, organic carbon, total nitrogen and available phosphorus are also low usually especially in previously cropped area. These low nutrients suggest an early need for fertilizers when oil palms are planted on these soils.

The basement complex soils are shallow with sandy surface and gravelly or concretionary weakly developed, clayey sub soils. They have a higher base status than the Acid Sands. Thus, the basement complex soils of the South Eastern Nigeria are more acid compared to that of the Western Nigeria because of higher rainfall. Both zones are however low in available phosphorus. The soils of the Niger Delta

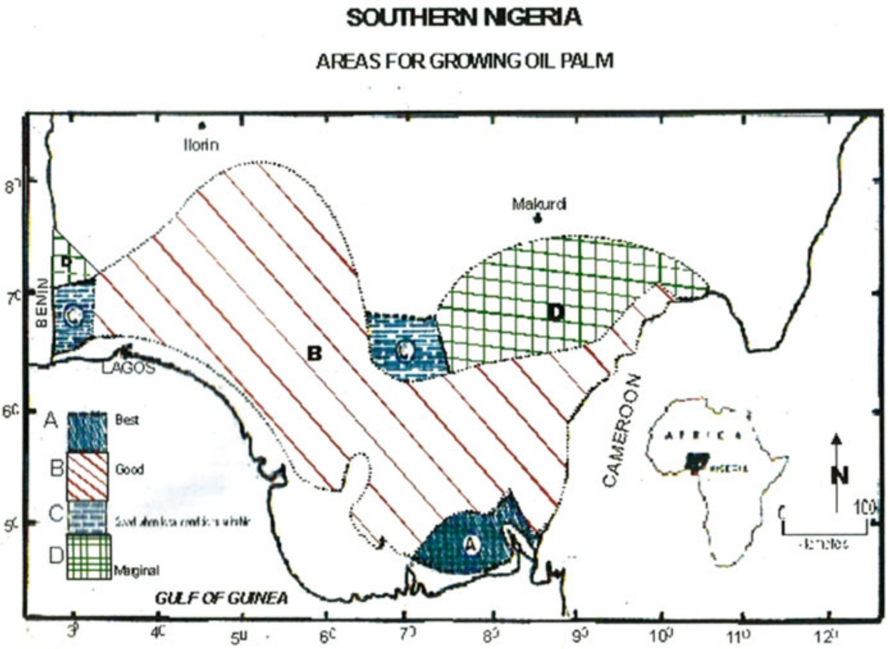

Fig. 17.1 Suitability classification of the oil palm belt in southern Nigeria

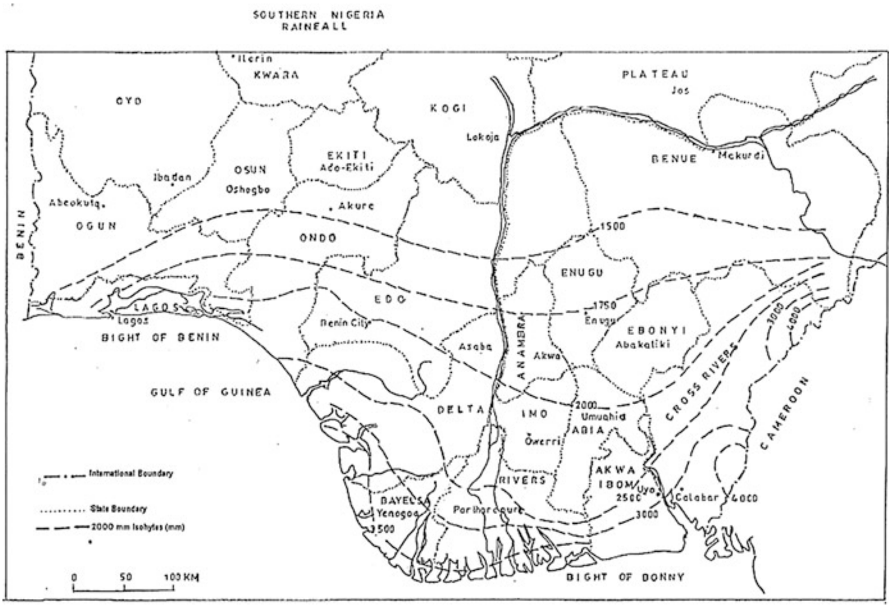

Fig. 17.2 Rainfall in southern Nigeria

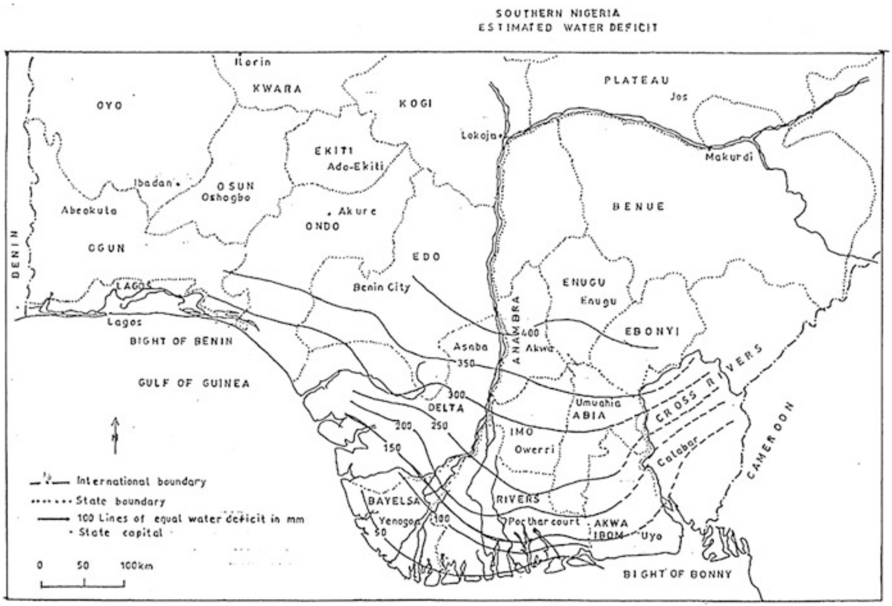

Fig. 17.3 Soil moisture deficit in southern Nigeria

(Sombreire -Warri Deltaic Plain soils) are low in magnesium, potassium, and phosphorus and are strongly acid in reaction (Omoti et al. 1987).

These soils as with tropical soils are fragile and require careful management to sustain their structure, fertility and productivity (Nye and Greenland 1960). Consequently it is necessary to put in place adequate soil management practices to ensure optimum crop yield. This factor is very well recognized in the oil palm. Climatic and soil conditions for oil palm cultivation are summarized in Table 17.1.

17.2 Essential Mineral Elements and Nutrition of the Palm

Studies by Bull (1961), Southern (1967), Corley and Mock (1972), Ng et al. (1974), Ataga et al. (1981) have shown that nearly all the mineral elements which are essential for the growth of flowering plants are necessary for the normal growth and reproduction of oil palm and coconuts. The physiological functions of these elements in the palms are assumed to be similar to those in other flowering plants. For oil palm and nitrogen, phosphorus, potassium and magnesium are believed to stimulate and enhance vegetable growth and influence production. Factors such as earliness in commencement of bearing, number of inflorescences, sex ratio, number and weight of fruit or bunches, effects on bunch characteristics as decreasing the percentage of under-ripe fruits (Ojuederie 1977).

Table 17.1 Land and climatic characteristics for suitability classes for oil palm cultivation

Suitability classes						
Land & climatic characteristics	S11	S12	S2	S3	N1	N2
Score (%)	95–100	85–95	60–85	40–60	25–40	0–25
Climate						
Mean annual. Rainfall(mm)	> 2000	> 1700–2000	> 1450–1700	> 1250–1450	–	< 1250
Length of dry season(months)	> = 1	1–2	2–3	3–4	–	> 4
Mean ann. Temp (^{o} C)	> 29	27–29	24–27	22 24	–	< 22
Topography (T) slope(S) (%)	0–4	4–8	8–16	16–30	–	> 30
Wetness (w): Flooding	F0	F0	F1	F2	–	F3
Drainage	Perfect	Mod. To well	–	Poor, aeric	Poor drainable	Very poor not drainable
Soil physical characteristics (S)						
Texture	CL, SCL, L	CL, SCL, L	SCL – L	SCL – LFS	ANY	C,CS
	Blocky	Blocky	–	–	–	Massive single grain
Coarse fragmentation (vol. within 100 cm (Z)	> 3–10	10–15	15–35	35–55	–	> 55
Depth (cm)	> 100	90–100	50–90	25–50	–	< 25
Fertility characteristics(F)						
CEC (meq/100 g)	> 16	15–16	< 15	–	–	–
Base saturation (BS %)	> 35	20–35	< 20	–	–	–
pH	5.5–6.0	5.5–6.0	6.0–6.5	6.5–7.0	< 4, > 7.0	< 4, > 7.0
Organic matter (% OC, 0 – 15 cm)	> 1.2	1.2–0.8	< 0.8	–	–	–
Salinity (EC)	< 1	< 1–2	> 2–3	>3–4	> 4–8	> 38

Legend: FO = No flooding, F1 = 1–2 flooding months in ≥ 10 years, F2 = not more than 2–3 months in 5 years out of 10, F3 = 2–4 months every year, F4 = > 4 months in almost every year (Source: Sys 1985)

Table 17.2 Nutrient removal, immobilization and turnover in oil palms (in kg/palm year) on an acid sand soil in Nigeria

Nutrient state	N	P	K	Mg
Nutrient removal by 12 month old nursery oil palm seedlings	0.0021	0.0003	0.003	0.00034
Nutrient removed in bunch	0.200	0.040	0.230	0.030
Nutrient immobilized in palms	0.180	0.024	0.110	0.104
Nutrient turnover in fronds, male inflorescences, etc.	0.630	0.073	0.380	0.250
Mean total nutrient uptake. (kg/palm/year).	1.010	0.137	0.720	0.384

Source: Tinker and Smilde (1963a, b)

In the oil palm resistance to certain diseases (e.g. the vascular wilt disease in the oil palm) are improved by the application of potassium. Both potassium and chlorine are also important in the water economy of oil palm through participation in the mechanism of stomatal movement and osmo-regulatory adaptation of the palms to water stress (Beringer 1980; Von Uexkull 1985).

Deficiency of some of the essential elements like N, K, Mg and B give rise to clear deficiency symptoms. Detail descriptions of these deficiency symptoms for oil palm are to be found in Bull (1961).

17.2.1 Soil Nutrient Losses and Immobilization Following Oil Palm Establishment

Nutrient removal studies through total plant analysis have shown that for the oil palm (Tinker and Smilde; Lucas et al. 1979), potassium and nitrogen are in the greatest demand for growth and fruit production while the demand for phosphorus, magnesium and calcium are much lower. A nutrient removal figure for the oil palm is given in Table 17.2. The figures show that of the total potassium uptake per annum, about 50% is removed in the bunches or immobilized in trunk for the oil palm. Because the oil palm bunch refuse which contain high K levels are usually not returned to the plantations, the potassium loss can be substantial with time. A very high proportion of the phosphorus for oil palm is also diverted to the bunches and fruit respectively.

In the oil palm, studies on the annual nutrient uptake (Ng 1977) from the time of planting to maturity have shown a very sharp rise in nutrient uptake (particularly K) from the second year of planting. This finding has focused on the critical importance of adequate nutrition during immaturity if early harvests are to be large and rapid rising trend sustained which will bring earlier returns on investment.

17.2.2 Background of Fertilizer Trials Studies and Response by the Oil Palm

Observations made in 1940 about decline in yield of mature oil palm plantations awakened the need for research in soil fertility management in Nigeria. The declines in yield of the palms then were suspected to be a consequence of loss in soil fertility exhibiting symptoms associated with potassium deficiency (Toovey 1948). The depletion of soil nutrients were thought to be a result of burning the forest before planting or the continual harvesting of bunches and removal of bunch refuse from the site (Sheffield and Toovey 1941; Toovey 1948). Consequently, earlier studies attempted to elucidate the influence of soil cover management on soil fertility maintenance. Such studies have been reported in detail by Tinker and Ziboh (1959), Tinker (1963).

17.2.2.1 Soil Changes Following Oil Palm Plantation Establishment

Soil fertility decline in plantations established from high secondary forest may often not be significant during the first 5 years (Kowal and Tinker 1959), perhaps as a result of return of considerable amount of nutrients from the felled forest. However, serious depletion of exchangeable potassium and relatively smaller amounts of magnesium, and calcium is of consequence following plantation establishment on the Acid sands (Tinker 1963). A 5 × 5 Latin square experiment was laid out in 1940 at the Oil Palm Research Station (OPRS), now Nigerian Institute for Oil Palm Research (NIFOR) Main Station to investigate various methods of maintaining palms (Tinker 1963). These were:

A. Two years intercropping
B. Intercropping to exhaustion
C. Normal maintenance (cut-lasing) of cover
D. Neglected cover and
E. Leguminous cover, normally maintained

Results of these studies showed that when the plantation was established without burning, there was a rapid release of K from the vegetation followed by substantial increase in Mg and Ca in the topsoil. Initial K build up in the burnt plots were larger than in the un-burnt plots, although this difference was not noticeable after the 5 year. Although, Tinker did not find significant changes in organic matter content of the soil in the Benin fascs unless where inter-cropping or soil tillage was practiced, this conclusion did not hold for the poorer Calabar soils. Soil changes occurring under the various covers following oil palm cultivation are presented in Tables 17.3 and 17.4. After the 5 year, gradual and significant reductions of all cations were noticeable over the next 15 years. The most significant nutrient losses were found to be in potassium. Magnesium and calcium losses were also substantial. These results indicated that tilling or putting the soils under cover a natural bush or *Pueraria* cover was not effective in soil fertility conservation with respect to oil palm growth.

Table 17.3 (**A**) Effect of oil palm cultivation on the chemical status of surface soil (0–15 cm) from an experiment at the NIFOR main station under *Pueraria* Cover. (**B**) Effect of oil palm cultivation on the chemical status of surface soil (0–15 cm) from an experiment at the NIFOR main station under weed cover

Age of palm (years)	pH	C %	N %	Exchangeable Cations K	Ca	Mg	CEC	Available P mg/kg
				meq/100 g				
1	5.86	0.92	0.083	0.121	3.22	0.80	4.94	–
5	5.91	0.97	0.080	0.129	3.82	0.80	5.18	–
10	5.48	0.92	0.90	0.091	2.76	0.56	4.50	–
15	5.60	1.07	0.074	0.072	2.86	0.62	5.10	–
20	5.86	0.92	0.073	0.048	2.26	0.56	4.50	–
1	6.20	1.06	0.08	0.135	4.26	0.83	5.78	–
5	6.69	1.08	0.09	0.184	5.16	0.90	6.24	–
10	6.04	1.07	1.10	0.094	3.61	0.74	5.30	–
15	6.00	1.04	0.075	0.062	3.69	0.77	5.60	–
20	6.29	1.02	0.081	0.045	3.45	0.60	4.90	5.7

Table 17.4 Exchangeable cation loss from cover plots C, D & E

	K		Mg		Ca	
Depth (cm)	0–38	38–117	0–38	38–117	0–38	38–117
Highest level, 1945 or 1951	0.153	0.091	0.85	0.58	4.36	2.29
Lowest level, 1961	0.045	0.025	0.58	0.30	2.95	1.67
Loss	0.109	0.066	0.27	0.28	1.41	0.62
Loss in kg per hectare	99	115	73	150	645	549

Tinker (1963)

17.2.3 Responses to Potassium, Nitrogen and Magnesium Fertilizers Early Trials (1937–1970)

Ataga et al. (1981) extensively reviewed the status of research on soil fertility management in the oil palm in the Acid Sands of Nigeria. In Nigeria, research on soil fertility management in the oil palm commenced with exploratory experiments about 1937. The first properly designed trials were conducted between 1940 and 1959. Further trials were conducted between 1959 and 1970.The first phase of the soil fertility management trials conducted between 1937 and 1945 sought to test the ***effects of the presence or absence and the different fertilizer types on growth and yield of the oil palm.*** Doses of fertilizer ranging from 4.5 to over 10 kg of each fertilizer were given per palm either as single dose or repeated over several years, While responses to K and Mg were obtained on previously cropped areas or on bearing palms where visible deficiencies already existed. In all cases there were no significant responses to nitrogen, phosphate or lime applications. These studies were followed by a series of 3^nNPK factorial trials and with occasional inclusion of calcium or magnesium. **These experiments investigated the rates, frequencies and time of fertilizer applications** on the Benin, Calabar fascs and intergrade soils. These experiments were located at the Cowan Estate near Sapele (started in 1940), Umudike, Akwete, Nkwelle and the then WAIFOR Main Station (now NIFOR). In the Umudike experiments on 23 years old palms, N as sulphate of ammonia, P as superphosphate and K as potassium chloride were applied at the rates of 62 kg and 1255 kg of these compounds per hectare. The experiments at Akwete were laid on a highly K and Mg-deficient soils and investigated three frequencies (annual, biennial, triennial) of application and time of application. In the experiments at the West African Institute for Oil Palm Research (WAIFOR) Main Station farm yard manure was included as one of the fertility treatments.

May (1956b) reviewed and summarized the findings of these experiments as follows**:**

- **Potassium** requirement: Potassium need of the palm is widespread. In old plantings with deficiency, dressing up to 4 kg per palm may be needed for full responses. There may be no potassium requirement for several years in areas opened from secondary forest and annual dressings of about 1 kg per palm will be sufficient. Broadcasting seemed to be a more satisfactory method of placement. Potassium applications induced magnesium deficiency. on poor Acid Sands soils.
- **Nitrogen:** Nitrogen dressings are important in the early years usually in the order of 225 g per palm in the year of planting and thereafter 450 g per palm per year of age for 3 or 4 years.
- **Phosphorus:** Phosphorus is required in the basement complex soils and on Acid Sands. It is only important in the Acid Sands after several years of bearing.
- **Farm yard manure:** Although yield responses to organic manure in the form of farm yard manure or bunch refuse can be obtained, refuse incinerated in the form of ash is just as effective, and less expensive to apply and can supply a small but significant proportion of potassium needs.
- **Timing of application:** Applications of fertilizer are most advantageous early in the rains and there is no advantage in dividing the dressing into several small doses.

Following from these experiments further trials were set up from about 1955 using well known genetic materials to investigate **rates of application, frequencies, interactions between nutrients, effects of micronutrients, effects of soil types.** These experiments were of 4 m x 2n design in which the nutrients of interest particularly K and Mg were tested at four rates while P and the micronutrients were tested at two rates. Generally these results of these studies followed the same pattern of the earlier experiments. However, there were indications of Boron requirement in the presence of Mg on the Benin fasc or only in the presence of P on the Calabar fasc. Interactions involving potassium, phosphorus and nitrogen were observed and suggested that application of phosphorus or nitrogen fertilizers alone in the absence of potassium decreases yield whereas with K in the presence of adequate N or P full response to K was obtained.

17.2.4 Further Fertilizer Trials

Further fertilizer trials commenced in 1971 in different ecologies of the Acid sands to determine more precise recommendations. These trials were laid out as $^1/_4$ replicates of confounded factorials, involving higher doses of fertilizer and four frequencies of application.

These trials were inconclusive as most of the data remained unpublished and the interactions were not clearly understood.

17.2.5 Response by Oil Palm to Locally Sourced Mineral Materials as Fertilizers

Fertilizer trials using locally sourced mineral materials commenced in about 1999 in Nigeria (Isenmila et al. 2003; Imogie et al. 2012). The experiments were largely performed using the NIFOR Extension Works Seeds (EWS) at the Okomu Oil Palm Estate in Edo State Nigeria. The results of the trials are as presented;

Experiment 1 Evaluation of locally sourced rock phosphate bearing mineral as $P_2O_{5.}$ A field trial was initiated in 1999 on 6 year ol NIFOR EWS tenera oil palms planted on Rhodic palendualf soil series. Three sources of phosphorus, namely single super phosphate (SSP), Sokoto Rock Phosphate (SRP) and crystallizer super fertilizer (CRY) and Sub pilots: The sub plots consists of three rates of fertilizer application such as. SSP at 1.0 kg, 2.0 kg and 3.0 kg/palm/year SRP at 1.5 kg, 2.5 kg and 3.5 kg/palm/year and CRY at 1.5 kg, 2.5 kg and 3.5 kg/palm/year respectively. Basal application of N as Urea at 0.5 kg/palm/year, K as MOP at 2.0 kg/palm/year was applied to all treatment palms except the control that is nil. Data on fresh fruit bunches (FFB) are being collected on fortnight bases.

Experiment 2 Evaluation of locally sourced rock bearing potassium mineral as K sources for oil palm cultivation. The treatments are as shown in Table 17.5.

Experiment 3 Evaluation of locally sourced rock bearing magnesium mineral as magnesium source for oil palm cultivation. The treatments were laid down in the field (Okomu Oil palm plantation) as randomized complete block design (RCBD) replicated three times and evaluated at three rates respectively as indicated in Table 17.6.

17.2.6 Nitrogen Fertilizer

The effect of four sources of nitrogen fertilizer on oil palm growth and yield were investigated on acid sand soils, in a field cleared from secondary forest. The results

Table 17.5 Evaluation of locally sourced rock bearing potassium mineral as K sources for oil palm cultivation at the Okomu Oil Palm Estate in Edo State Nigeria

Treatments	Types of fertilizer (kg/palm/year)	Rates of applied (Kg/palm/year)
1.	Nil	0
2.	BD + MOP	1.0
3.	BD + MOP	1.5
4.	BD + MOP	2.0
5.	BD + MOP	2.5
6.	BD + PRM	1.5
7.	BD + PRM	2.25
8.	BD + PRM	3.0
9.	BD + PRM	3.75

Key: *BD* Basal Dressing; *MOP* Murate of Potash; *PRM* Phosphate rock mineral

Table 17.6 Evaluation of locally sourced rock bearing magnesium mineral as magnesium source for oil palm cultivation (Okomu Oil Palm Estate Edo State)

Treatment	Types	Rates of application
1.	Control	0 kg
2.	Kieserite + BD	0.5 kg/palm/year
3.	Kieserite + BD	1.0 kg/palm/year
4.	Kieserite + BD	1.5 kg/palm/year
5.	Magnesite + BD	0.5 kg/palm/year
6.	Magnesite + BD	1.0 kg/palm/year
7.	Magnesite + BD	1.5 kg/palm/year
8.	Calcined Mg + BD	0.5 kg/palm/year
9.	Calcined Mg + BD	1.0 kg/palm/year
10.	Calcined Mg + BD	1.5 kg/palm/year
11.	Dolomite + BD	1.0 kg/palm/year
12.	Dolomite + BD	1.0 kg/palm/year
13.	Dolomite + BD	2.0 kg/palm/year

Key: *BD* Basal Dressing; *Mg* Magnesium

showed that, irrespective of the sources, vegetative growth of oil palm was enhanced but no significant effect was recorded on fresh fruit bunch yield. Therefore, for oil palm fertilization any source of nitrogen could be used for establishment and early growth.

17.2.7 Effect of Local Rock Minerals on Fresh Fruit Bunch Production (Ffb t/ha)

The results from the above trials show that oil palm fresh fruit bunch production responded positively to application of various sources of local rock minerals. Response of fresh fruit bunch to local rock mineral was more as bunch number than the single bunch weight. (Figs. 17.4, 17.5, 17.6, 17.7, 17.8, 17.9, 17.10, 17.11, 17.12 and 17.13).

17.2.8 Phosphorus Sources

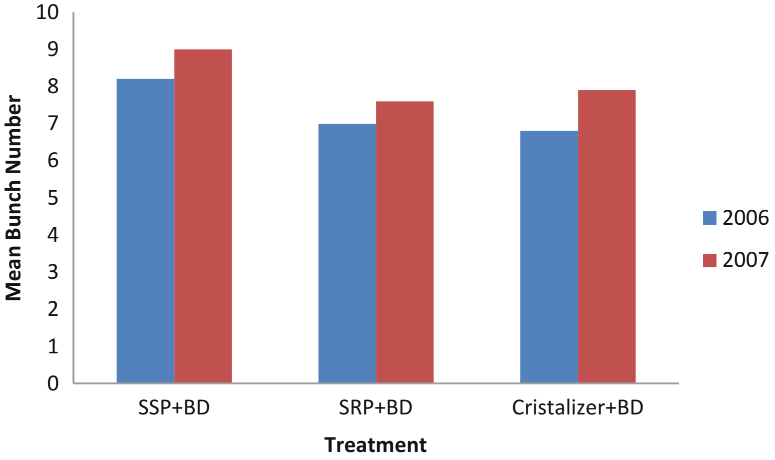

Fig. 17.4 Effect of phosphorus sources and rates on mean bunch number (2006–2007)

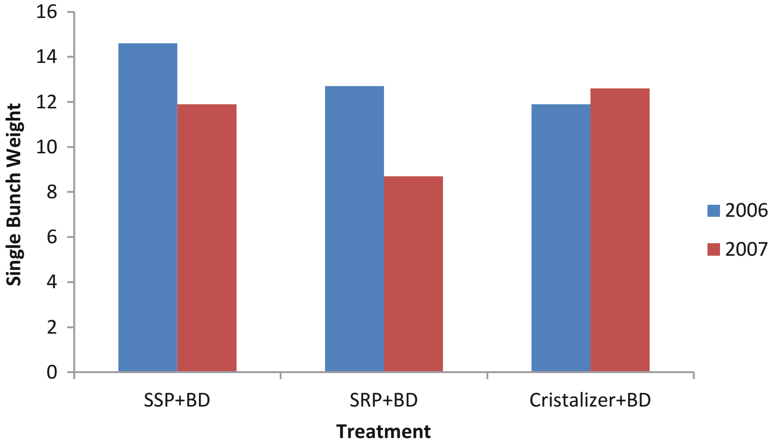

Fig. 17.5 Effect of phosphorus sources and rates on single bunch weight (2006–2007)

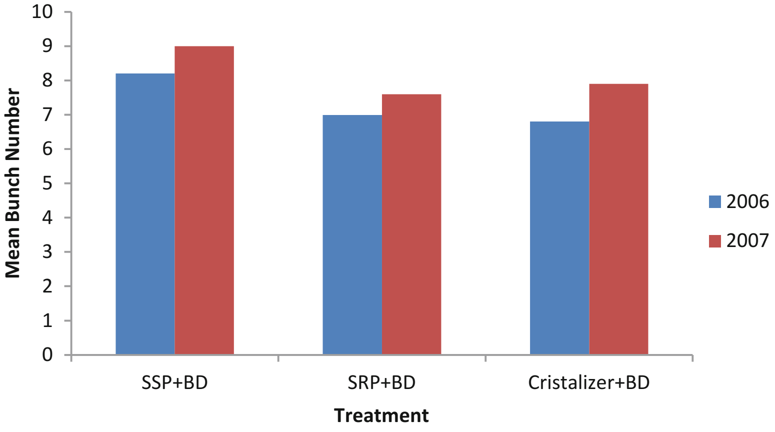

Fig. 17.6 Effect of phosphorus sources and rate on mean bunch number (2006–2007)

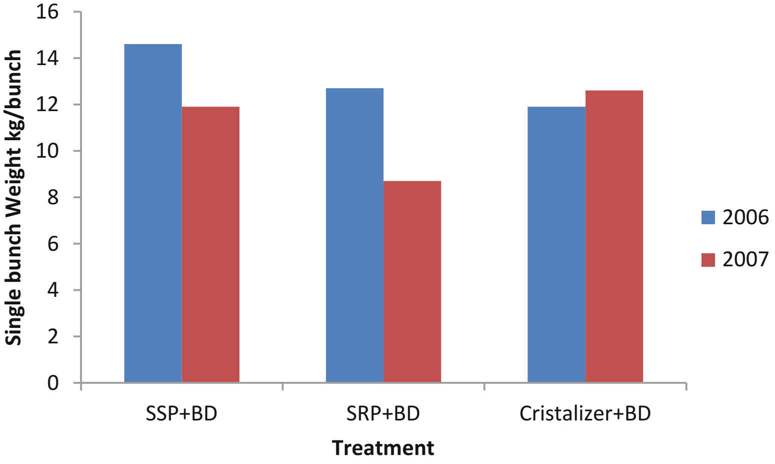

Fig. 17.7 Effect of phosphorus sources and rates on single bunch weight (kg/bunch) (2006–2007)

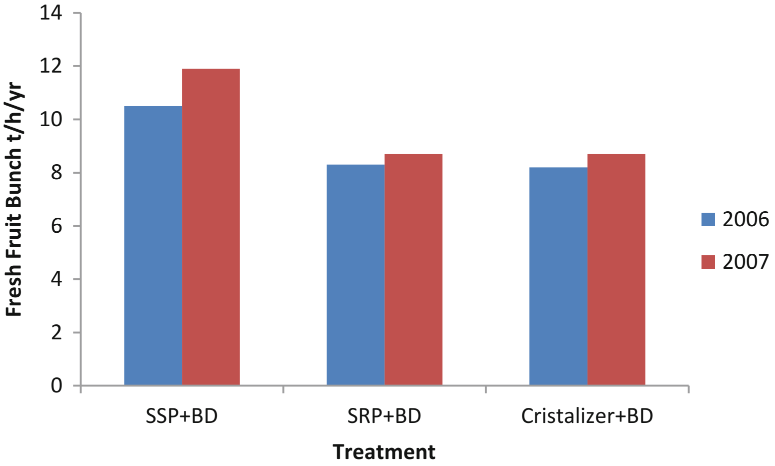

Fig. 17.8 Effect of phosphorus sources and rates on fresh fruit bunch production (t/h/year) (2006–2007)

17.2.9 Magnesium Sources

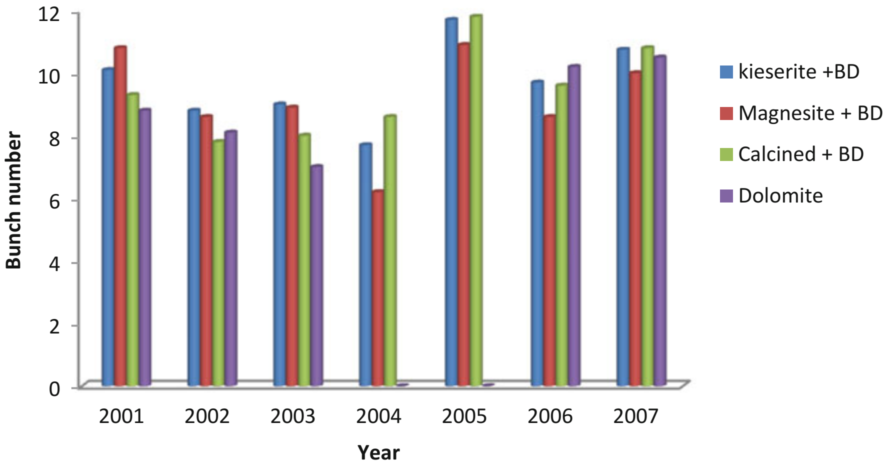

Fig. 17.9 Average effect of magnesium sources and rate on the oil palm bunch number (2001–2007)

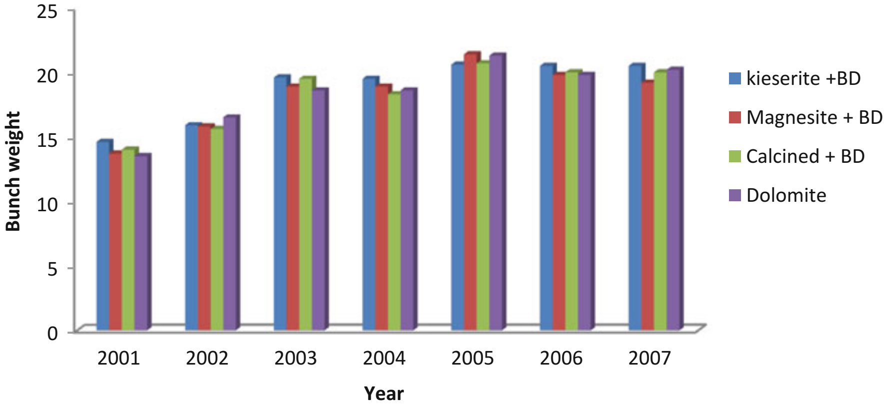

Fig. 17.10 Effect of magnesium sources and rates on oil palm single bunch weight (kg) (2001–2007)

17.2.10 *Potassium Rock Mineral Sources*

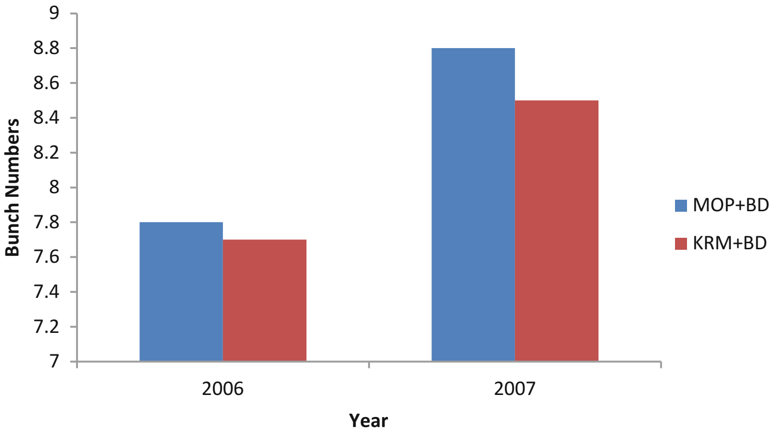

Fig. 17.11 Effect of Potassium sources on bunch number (2006–2007)

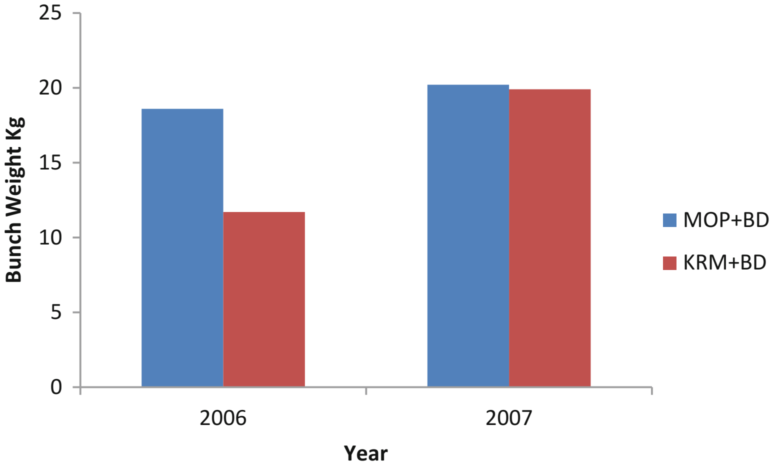

Fig. 17.12 Effect of Potassium sources on bunch weight (Kg) (2006–2007)

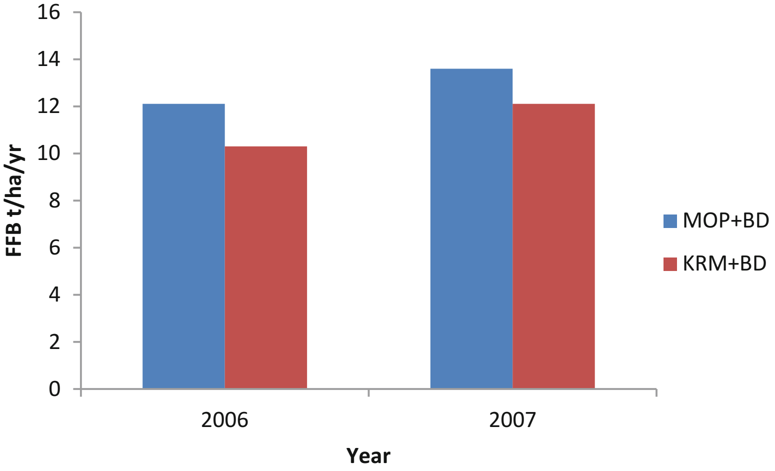

Fig. 17.13 Effect of Potassium sources on fresh fruit bunch (t/ha/year) (2006–2007)

17.2.11 Fertilizer Recommendation for Oil Palm

The existing fertilizer recommendations in Nigeria are based on trials, which commenced between 1960 and the early 1970's with NIFOR *tenera* progenies with potential yield of less than 12 tonnes fresh fruit bunch (FFB)/ha/year.

Results of these old fertilizer trials emphasized soil and site specificity in their fertilizer requirements (Ataga and Omoti 1978). One or more of the elements N, P, K, and Mg are usually in high demand for optimum yield (Tinker 1963; Hartley 1988*)*. However, the new generation elite *tenera* materials which are now being released by NIFOR (since 1984) and which constitutes the bulk of the materials planted in recently opened plantations are capable of producing between 18 and 25 tonnes/ha/year ffb. It is expected that the nutrient demands of these new materials would be higher than materials of the earlier period. As the soils of the oil palm belt are usually deficient in the primary nutrients (Hartley 1988), it is important to determine nutrient requirements of these new oil palm materials on well-defined soils.

Although fertilizer recommendations for the oil palm have been made on a broad scale, the need to determine soil-series specific fertilizer requirement for the crop in Nigeria has long been recognized. The fertilizer requirement of the new NIFOR Elite *tenera* materials has been determined. These materials, which yield higher than older materials, are being established extensively on different soils of the oil palm belt. Furthermore, for maximum yield and economic returns, field trials are necessary to determine the correct amount and ratio of the various nutrients for particular or specific soil types.

The various fertilizer recommendations for oil palm cultivation in Nigeria are outlined (Tables 17.7, 17.8, 17.9, 17.10, 17.11 and 17.12)

Table 17.7 Fertilizer recommendation for oil palm on the moderately acid sands of the forest zone (1700–2000 mm/year rainfall)

Nutrient/ha	Source	Kg per palm	Kg per ha	
6.67 kg N	Urea	0.1	14.5	Year of transplanting i.e. year 0
6.5 kg P_2O_5	SSp	0.25	26.3	
34.8 kg K_2O	MOP	0.40	58.0	
2.30 kg MgO	Kieserite	0.1	14.5	
	Compound 12-12-17-2MgO or 15-15-15	0.25	36.3	36 0.3 kg 12-12-17-2 or 15-15-15 per ha
13.34 kg N	Urea	0.2	29.0	1st year after transplanting
13.05 kg P_2O_5	SSP	0.5	72.5	
34.8 kg K_2O	MOP	0.5	72.5	
2.32 kg MgO	Kieserite	0.2	29.0	
	Compound 12-12-17-2MgO or 15-15-15	0.5	72.5	
33.35 kg N	Urea	0.5	72.5	2nd year after transplanting
26.1 kg P_2O_5	SSP	1.0	145	
87 kg K_2O	MOP	1.5	217.5	
5.8 kg MgO	Kieserite	0.5	72.5	
	Compound 12-12-17-2MgO or 15-15-15	1.0	145	

(continued)

Table 17.7 (continued)

Nutrient/ha	Source	Kg per palm	Kg per ha	
33.4 kg N	Urea	0.5	72.5	3rd year after transplanting
39.2 kg P_2O_5	SSP	1.5	217.5	
174.0 kg K_2O	MOP	2.0	290.0	
17.4 kg MgO	Kieserite	0.75	108.8	
	Compound 12-12-17-2MgO or 15-15-15	1.5	217.5	

Fertilizer application in subsequent years would depend on results from soil and foliar analysis. In the mature years, MOP needs would range from 1.5–4.5 Kg per palm, and 1.5 kg per palm kieserite Urea 0.5 kg per palm and SSP 1 kg per palm

Table 17.8 Fertilizer recommendation for oil palm on the relatively wet acid sands of the forest zone (2000–3000 mm/year rainfall)

Nutrient/ha	Source	Kg per palm	Kg per ha	
16.7 kg N	Urea	0.25	36.6	The year of transplanting into the field
6.53 kg P_2O_5	SSP	0.25	36.3	
43.5 kg K_2O	MOP	0.25	36.3	
2.32 kg MgO	Kieserite	0.1	14.5	
	12-12-	0.25	36.3	
	17 + 2MgO or			
	15-15-15			
16.70 kg N	Urea	0.25	36.3	The 1st year after transplanting into the field = 16.7 kg N + 13.05 kg / p_2O_5 + 43.5 kg K_2O + 72.5 kg 12-12-17 + 2 MgO or 15-15-15 per hectare
13.05 kg P_2O_5	SSP	0.5	72.5	
43.5 kg	MOP	0.5	72.5	
MgO	Kieserite	0.5	72.5	
	12-12-17 + MgO or 15-15-15	0.5	72.5	
33.25 kg N	Urea	0.5	108.8	The 2nd year after transplanting into the field
26.1 kg P_2O_5	SSp	1.50	217.5	
87 kg K_2O	Kieserite	1.0	145	
11.6 kg MgO	12-12-17 + MgO or	0.5	36.3	
	15-15-15	0.75	108.8	
33.4 kg N 39.2 kg	Urea	0.5	72.5	For the 3rd year after transplanting into the field
P_2O_5 174.0 kg K_2O	SSP	1.5	217.5	
23.2 kg MgO	MOP	2.0	290.0	
Compound fertilizer	Kieserite	1.0	145	
	12-12-17 + 2 MgO or 15-15-15	1.5	217.5	

Fertilizer application in subsequent years would be determined by results of soil and foliar analysis

Table 17.9 Fertilizer recommendation for oil palm on the basement complex soils of South Eastern Nigeria

Nutrient/ha	Source	Kg per palm	Kg per ha	
3.34 kg N	Urea	0.05	7.25	The year of transplanting into the field
2.61 kg P_2O_5	SSP	0.1	14.5	
21.78 kg K_2O	MOP	0.25	36.3	
	Kieserite	0.5	72.5	
6.68 kg N	Urea	0.1	14.5	The 1st year after transplanting into the field
6.53 kg P_2O_5	SSP	0.25	36.3	
43.5 kg K_2O	MOP	0.5	72.3	
17.4 kg MgO	Kieserite	0.75	108.8	
	12-12-17 + MgO or 15-15-15	0.25	72.5	
13.3 kg N	Urea	0.2	29.0	The 2nd year after transplanting into the field
13.05 kg P_2O_5	SSP	0.5	72.5	
43.5 kg K_2O	MOP	0.5	72.5	
30.2 kg MgO	Kieserite	1.3	188.5	
Compound fertilizer	12-12-17 + 2 MgO or 15-15-15	0.75	108.8	
16.7 kg N	Urea	0.25	36.25	For the 3rd year after transplanting into the field
15.7 kg P_2O_5	SSP	0.6	87.0	
65.3 kg K_2O	MOP	0.75	108.8	
46.4 kg MgO	Kieserite	2.0	290.0	
Compound fertilizer	12-12-17 + 2 MgO or 15-15-15	1.5	217.5	

Fertilizer application in subsequent years would be determined by results of soil and foliar analysis

Table 17.10 Fertilizer recommendation for oil palm on the soils of the sub-recent terrace (Sombreiro – Warri deltaic plain)

Nutrient/ha	Source	Kg per palm	Kg per ha	
13.34 kg N	Urea	0.2	29.6	The year of transplanting into the field = 13.3 kg N + 6.5 kg P_2O_5 + 43.5 kg MgOha^{-1}. Or 36.3 kg 12-12-17 + 2 MgO or 15-15-15 per hectare
6.5 kg P_2O_5	SSP	0.25	36.3	
43.5 kg K_2O	MOP	0.5	72.5	
4.64 kg	Kieserite	0.2	29.0	
MgO	12-12-17 + 2 MgO or 15-15-15	0.25	36.3	
13.34 kg N	Urea	0.2	29.0	The 1st year after transplanting into the field = 13.34 kg N + 9.28 kg P_2O_5 + 52.2 kg K_2O + 9.28 kg MgO per hectare or 72.5 kg 12-12-17 + 2 MgO or 15-15-15 per hectare
13.05 kg P_2O_5	SSP	0.5	72.5	
52.2 kg K_2O	MOP	0.6	87.0	
9.28 kg	Kieserite	0.4	58.0	
MgO	12-12-17 + 2 MgO or 15-15-15	0.5	72.5	

(continued)

Table 17.10 (continued)

Nutrient/ha	Source	Kg per palm	Kg per ha	
33.35 kg N	Urea	0.5	72.5	The 2nd year after transplanting into the field
13.05 kg $P2_05$	SSP	1.0	262.5	
52.2 kg K_2O	MOP	1.0	262.5	
9.28 kg MgO	Kieserite	0.5	362.5	
	12-12-17 + 2 MgO or 15-15-15	1.0	72.5	
66.7 kg N	Urea	1.0	145.0	For the 3rd year after transplanting into the
65.25 kg P_2O_5	SSP	2.5	362.5	
217.5 kg K_2O	MOP	2.5	362.5	
58 kg MgO	Kieserite	2.5	362.5	
	12-12-17 + 2 MgO or 15-15-15	2.0	290.0	

Fertilizer application in subsequent years would be determined by results of soil and foliar analysis

Table 17.11 Fertilizer recommendation for oil palm on the marginal areas of middle belt (1200–1500 mm/year rainfall)

Nutrient/ha	Source	Kg per palm	Kg per ha	
16.70 kg N	Urea	0.25	36.3	The year of transplanting into the field
6.53 kg P_2O_5	SSP	0.25	36.3	
21.78 kg K_2O	MOP	0.25	36.3	
2.32 kg MgO	Kieserite	0.1	14.5	
	12-12-17 + 2 MgO or 15-15-15	0.25	36.3	
33.25 kg N	Urea	0.5	72.3	The 1st year after transplanting into the field
13.05 kg P_2O_5	SSP	0.5	72.5	
34.5 kg K_2O	MOP	0.5	72.5	
4.644 kg MgO	Kieserite	0.20	29.0	
	12-12-17 + 2 MgO or 15-15-15	0.50	72.5	
49.59 kg N	Urea	0.75	108.8	The 2nd year after transplanting into the field
39.15 kg P_2O_5	SSP	1.50	217.5	
87 kg K_2O	MOP	1.0	145	
5.8 kg MgO	Kieserite	0.25	36.3	
	12-12-17 + 2 MgO or 15-15-15	0.75	108.8	
50.0 kg N	Urea	0.75	108.8	For the 3rd year after transplanting into the field
39.2 kg P_2O_5	SSP	1.5	217.5	
130 kg K_2O	MOP	1.5	217.5	
11.6 kg MgO	Kieserite	0.5	72.5	
Compound fertilizer	12-12-17 + 2 MgO or 15-15-15	1.5	217.5	

Fertilizer application in subsequent years would be determined by results of soil and foliar analysis

Table 17.12 Recommended rates for NPK, magnesium, compound fertilizer (12-12-17 + 2 MgO) for Oil Palm

Nutrient/ha	Source	Kg per palm	Kg per ha	
4.5 kg N	Compound fertilizer	0.25	37.7	6 weeks and 6 months after transplanting into the field = 4.5 kg ha^{-1} N + 4.5 kg ha^{-1} P_2O_5 + 6.4 kg ha-K_2O + 0.8 kg ha^{-1}1K_2O ha^{-1} MgO
4.5 kg P_2O_5				
6.4 kg K_2O				
0.8 kg MgO				
9.0 kg N	Compound fertilizer	0.5	75	1st year after transplanting into the field early in the rains = 9.0 kg ha^{-1} P_2O_5 + 12.8 kg ha^{-1}K_2O + 1.6 kg ha^{-1} MgO
9.0 kg P_2O_5				
12.8 kg K_2O				
1.6 kg MgO				
13.5 kg N	Compound fertilizer	0.75	112.5	2nd year after transplanting into the field = 13.5 kg ha^{-1} N + 13khg ha^{-1} P_2O_5 + 19.2 kg ha^{-1} K_2O + 2.4 kg ha^{-1} MgO
13.5 kg P_2O_5				
19.2 kg K_2O				
2.4 kg MgO				
36 kg N	Compound fertilizer	2.0	300	The 3rd year and onwards year after transplanting into the field = 36 kg ha^{-1} N + 36 kg ha^{-1} P_2O_5 + 51 kg ha^{-1} K_2O + 6 kg ha^{-1} MgO
36 kg P_2O_5				
51 kg K_2O				
6 kg MgO				

Source: Chude 2012: Fertilizer use and management practices for crops in Nigeria 4th Edition. Federal Fertilizer Department, Federal Ministry of Agriculture and Rural Development, Abuja

17.3 Conclusion

Arising from the present review of studies on fertilizer response by the oil palm in Nigeria, the following deductions can be made;

- The studies were conducted on soils typical of the oil palm growing region of Southern Nigeria.
- The soils under investigation had insufficient amount of the essential nutrients required for the vegetative and reproductive growth of the oil palm.
- The oil palm responded to various rates, types and sources (locally sourced) fertilizer applications especially with respect to potassium, nitrogen, phosphorus and magnesium, while there was need for micronutrient applications to the soils.
- There is also inadequate and unavailable information on the residual levels of the fertilizer elements long after application and uptake by the oil palm.

17.3.1 Recommendation

In the light of the aforementioned,

There is need to ensure adequate supply and quality certification of fertilizers used for the various trials.

- The studies on oil palm response to fertilizers in Nigeria should be extended to the other parts of the country which is perceived to be marginal in terms of soil and climatic conditions for oil palm cultivation.
- Following recent changes in climatic conditions, there is need to re-establish the earlier trials which gave rise to the present fertilizer recommendation for oil palm cultivation.

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Chapter 18
An Assessment of Inherent Chemical Properties of Soils for Balanced Fertilizer Recommendations for Cocoa in Ghana

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Abstract Sustainable cocoa production in Ghana would require a shift in fertilizer recommendations from general applications to site-specific recommendations of fertilizers that account for initial fertility status and actual nutrient needs of soils on which cocoa is grown. A soil fertility survey was conducted in the major cocoa regions of Ghana covering the major benchmark soils. Two hundred and twenty four plots were sampled and composite surface soils collected and analyzed for selected fertility characteristics. The results show that most of the cocoa soils have low inherent fertility characterized by low C, N and exchange capacity. All the cocoa soils sorb P, which may limit availability of P in the soil solution. The soils generally are acidic, and soils in Western region, especially the Ferralsols, show the most acidic reaction with substantially measurable exchangeable Al. The results suggest that these differential characteristics of the surveyed soils should be considered in formulating balanced site-specific fertilizer for cocoa in Ghana.

Keywords Soil • Fertilizer recommendation • Fertility • Cocoa

Contents

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18.1 Introduction

Cocoa production represents a mainstay to the Ghanaian economy. Traditionally cocoa is grown as a low input crop with little or no fertilizer application, which results in the long run in depleted soil fertility and reduced crop yield. In Ghana, nutrient budget under low input cocoa systems over a 75-year period revealed that up to 655,000 tons of N, 42,000 tons of P_2O_5 and 144,000 tons of K_2O were removed from the soil over that period of time, and that sustainable cocoa production in Ghana would require annual replacement of the nutrients exported by the crop (Afrifa et al. 2006).

The low input cropping system has been shown to be the driving force behind deforestation (Gockowski and Sonwa 2010). Numerous works have shown that encroachment on remnant forests would be spared, or greatly reduced, and better cocoa yield would be achieved if cocoa cultivation would be intensified through adoption of good agronomic practices including judicious fertilizer application.

The recent introduction of fertilizer use into cocoa cultivation in Ghana (Appiah et al. 2000) aims at maintaining soil fertility and sustaining crop productivity. However, the fertilizer proposed to cocoa farmers in Ghana is of a blanket formulation with a rate of application of approximately 150 kg acre^{-1} regardless of soil type and agroecological conditions (CRIG 2008). Although these fertilizer formulas lead to significant yield increase, especially in second and third year of application (Appiah et al. 2000), they are not supportive of sustainable cocoa production because they fail to account for the inherent characteristics of the various soil groups and agroecozones of the cocoa zones. Moreover, research results on cocoa nutrition in West Africa suggest the need for balanced ratio between nutrients, especially N and P on the one hand, and K, Ca and Mg on the other hand, to optimize cocoa productivity (Jadin and Snoeck 1985; Snoeck et al. 2006).

There is limited information on soil chemical characteristics that would help site specific formulation of fertilizer for cocoa in Ghana. As a first step towards improving fertilizer recommendation for cocoa in Ghana, information is needed on inherent soil fertility characteristics and nutrient needs in the various cocoa agroecologies of Ghana. The objective of this soil survey is to assess initial soil fertility and nutrient needs that would provide a basis for effective nutrient management for increased and sustainable crop productivity in Ghana.

18.2 Materials and Methods

18.2.1 Study Area and Site Selection

The survey was conducted in the semi deciduous forest and rain forest agroecological zones of Ghana located 8°00′N and 2°00′W in West Africa. The climate is a Sudan Guinean type with a bimodal rainfall regime with mean annual rainfall of

1500 mm in the deciduous forest zone, and 2200 mm in the rain forest zone. The soils are highly weathered and comprise Acrisols, Lixisols, Nitisols and Ferralsols soil units of the FAO soil classification.

Sites for soil sampling were selected in the seven administrative cocoa regions of Ghana (Brong Ahafo, Western North, Western South, Ashanti, Central, Eastern and Volta) essentially based on soil types while accounting for the total length of growing period (LGP) which is categorized as follows:

- LGP1 with LGP $>$ 330 days
- LGP2 with 330 days $>$ LGP $>$300 days
- LGP3 with 300 days $>$ LGP $>$270 days

For each region and for each soil type-LGP combination, 16–24 cocoa plantations with no fertilization history were proposed by farmers and confirmed for soil sampling.

A total of 224 sites where selected for soil sampling. Per site, cocoa plots were selected to encompass the following categories.

- 3–10 years
- 11–20 years
- $>$ 21 years

Farm environment including previous crop history and shade intensity, was described for each plot during soil sampling.

18.2.2 Soil Sampling and Analyses

Surface soil samples were collected at 0–20 cm depth along diagonals of a 20 m × 20 m quadrate representative of plot. On each plot, five soil monoliths were taken along the diagonals using an earth chisel, homogenized in a plastic bucket, and a composite sample of approximately 500 g was taken, air-dried, and sieved through a 2 mm screen. The sampling locations were recorded using a differential global position system unit (GPS). The sieved soils were kept in sealed plastic bags until they were analyzed.

Soil pH was determined with a glass electrode in 1:2.5 soil: water ratio. Particle size of samples was determined by the pipette method after destruction of the organic matter of samples with hydrogen peroxide H_2O_2 and dispersion with sodium hexametaphosphate $NaPO_3$ (Gee and Bauder 1986). Organic carbon C was determined by wet oxidation (Walkley and Black 1934). Total P was determined by the $HClO_4$ method (Kuo 1996). Available P was extracted by the Olsen method and determined colorimetrically by the molybdenum blue method (Murphy and Riley 1962). Exchangeable bases were extracted with NH_4oAc and determined by atomic absorption (Anderson and Ingram 1993). Exchangeable Al was extracted with 1 *M* KCl and determined by atomic absorption. Cation exchange capacity of soils was determined by the neutral ammonium acetate CH_3COONH_4 saturation method (Rhoades 1982). P sorption index of soils was determined by the Bache and Williams (1971) method. Micronutrients (Fe, Zn, Mn, Cu) were extracted with the Melich 3 extractant and determined by Inductively Coupled Argon Plasma spectrometry.

18.2.3 *Statistical Analysis*

Comparisons of soil parameters between soil units, cocoa regions or farm environmental conditions were done using PROC GLM (SAS Institute 1999).

18.3 Results and Discussion

18.3.1 *Major Soil Fertility Indices*

– *Textural class*

Soil physical analysis indicated that most of the soils of the cocoa regions of Ghana fall in the sandy clay loam category, although some few samples had loamy, clayey loam and loamy texture (Table 18.1). On a regional basis, Western region, Ashanti and Eastern regions had lower sand content and higher silt content than the other regions. Likewise, the percentage of sand was lower and that of silt was higher in the Acrisols and Ferralsols relative to the Lixisols and Nitisols.

– *Soil pH*

The pH in water varied from very acid (~5) to slightly acid (~6.5) in the cocoa soils (Table 18.2). Considering the four major cocoa soil groups, Nitisols had the

Table 18.1 Particle size distribution (0–20 cm) of selected Ghanaian cocoa soils, and different administrative regions

	Sand	Clay	Silt	Class
	%			
Regions				
Central	65.54	21.46	13.00	SCL
Brong Ahafo	61.24	21.11	17.65	SCL
Volta	54.57	20.53	24.88	SCL
Western	49.24	23.77	26.98	SCL
Ashanti	48.17	24.82	27.00	SCL
Eastern	47.79	25.18	27.02	SCL
Soils				
Lixisols	61.51	22.76	15.72	SCL
Nitisols	60.49	21.76	17.75	SCL
Ferralsols	50.70	21.96	27.33	SCL
Acrisols	49.65	23.92	26.42	SCL

SCL Sand Clay Loam

Table 18.2 Selected soil properties of top soil (0–20 cm) in the cocoa regions in Ghana

	pH	C	N	Ptot	Pavai
Soils					
Acrisols	5.66	1.53	0.15	393	10.6
Ferallsols	5.04	1.28	0.11	340	8.6
Lixisols	5.88	1.33	0.13	306	9.9
Nitisols	6.55	1.27	0.12	378	12.3
Pr > F	*0.001*	*0.07*	*0.005*	*0.001*	*0.14*
Regions					
Ashanti	6.06	1.61	0.17	438	12.6
Brong Ahafo	6.37	1.28	0.12	380	11.9
Central	5.83	1.30	0.13	278	10.6
Eastern	5.69	1.38	0.13	417	9.2
Volta	5.67	1.38	0.12	329	10.0
Western	5.25	1.56	0.14	347	9.6
Pr > F	*0.02*	*0.2*	*0.3*	*0.5*	*0.004*

Pavai = Extractible P; Ptot = Total P

less acidic soil (pH = 6.50) followed by the Lixisols (pH = 5.82), whereas the Ferralsols exhibited the lowest soil pH (5.01). Relating the pH values to the cocoa regions, it appeared that Ashanti and Brong Ahafo regions were associated with relatively higher pH values (> 6.0) whereas Western region soils had the lowest pH (5.23). These results suggest that soil acidity might be a major constraint to optimal crop production especially in Western cocoa regions of Ghana.

– *Soil C, N and P*

Mean soil C and N values were respectively 1.37 and 0.127% with the highest values obtained with the Acrisols (Table 18.2). There was no significant regional trend with regard to soil C. However, soils in the Ashanti region had the highest C content (1.61%). Soil N was highest in the Ashanti soils and lowest in the Volta soils (0.17 and 0.11 respectively).

Soil total P ranged from 277 to 430 mg kg^{-1}. Within soil units, the highest values were observed with the Acrisols (378 mg P kg^{-1}) followed by the Nitisols (355 mg kg^{-1}). There was no regional effect on total soil P content. However, soils from Volta and Central regions had the lowest total P content while soils from Eastern and Ashanti regions had the highest values. Mean values of available Olsen P was 11.9 mg P kg^{-1} and was highest in the Nitisols (12.30 mg kg^{-1}) and lowest in the Ferralsols (8.6 mg kg^{-1}). The regional effect was also significant ($P < 0.004$) with highest values recorded in Ashanti and Brong Ahafo regions while Eastern and Western regions exhibited the lowest values.

– *Exchangeable bases*

Exchangeable K varied from 0.06 cmol$_c$ kg^{-1} for the Ferralsols to 0.17 cmol$_c$ kg^{-1} with the Nitisols (Table 18.3). Regional analysis showed no significant trend. However, Western and Eastern regions experienced the lowest level of

Table 18.3 Base cations content of top soil (0–20 cm) in the cocoa regions in Ghana

	K	Ca	Mg	CEC	Al	^{a}Bsat	Al sat
	cmol$_c$ kg^{-1}					%	
Soils							
Acrisols	0.13	3.27	0.75	7.14	0.11	56.0	5.24
Ferallsols	0.09	1.28	0.29	5.54	0.30	30.2	31.60
Lixisols	0.14	3.82	0.94	5.84	0.02	83.5	1.08
Nitisols	0.17	4.26	0.72	7.48	0	70.3	0
Pr* > *F	0.02	0.2	0.02	0.06	0.63	0.002	0.0001
Regions							
Ashanti	0.15	4.36	0.95	7.72	0.05	74.8	2.33
Brong Ahafo	0.17	4.08	0.69	7.17	0.01	66.9	0.20
Central	0.18	3.80	0.95	5.40	0.1	91.0	1.90
Eastern	0.12	3.05	0.78	7.23	0.09	52.5	4.89
Volta	0.14	3.25	0.70	5.97	0.05	62.2	2.44
Western	0.11	2.37	0.55	6.52	0.19	42.8	15.00
Pr > *F*	*0.2*	*0.1*	*0.05*	*0.3*	*0.97*	*0.006*	*0.001*

^{a}*Bsat* Base saturation

exchangeable K. Overall these K levels were <0.2 cmol$_c$ kg^{-1}, and suggest the need for additional K fertilizer application in order to achieve optimal crop nutrition and growth.

Calcium followed a similar trend to that observed with K. The values obtained ranged from 1.21 cmol$_c$ kg^{-1} with the Ferralsols to 3.90 cmol$_c$ kg^{-1} for the Nitisols. Regional analysis showed lowest values in Western region and highest values in Ashanti and Brong Ahafo regions. Based on these values, Ferralsols and soils in Western region appeared to be deficient in calcium.

Magnesium values averaged 0.70 cmol$_c$ kg^{-1} and showed lowest values of 0.29 and 0.48 cmol$_c$ kg^{-1} in Ferralsols and soils in Western regions respectively.

– *Cation exchange capacity, aluminum saturation and base saturation*

Values of CEC observed for the major soils averaged 6.2 cmol$_c$ kg^{-1} and denote the highly weathered nature of Ghanaian cocoa soils. CEC values as low as 5.5 and 5.2 cmol$_c$ kg^{-1} were obtained with the Ferralsols and soils in Central region respectively (Table 18.3). Similarly, Al saturation was highest in the Ferralsols (31.6%) and nil in the Nitisols and reflected trends observed with soil pH. With regard to regional analysis, these values were lowest for Brong Ahafo soils (0.20%) and highest in the Western region soils (15.0%). The relationship with soil acidity and base saturation is evident. Acid soils are depleted of their bases which are replaced by Al cations on the exchange complex.

– *P sorption Index of soils*

Phosphate sorption index of the cocoa soils varied from 234 mg P kg^{-1} to 398 mg P kg^{-1} (Table 18.4). Considering the cocoa regions, Western cocoa soils

Table 18.4 Phosphate sorption index of Ghanaian cocoa soils (0–20 cm)

	PSI (mg kg^{-1})
Soils	
Ferralsols	398A[a]
Acrisols	329B
Nitisols	288B
Lixisols	246B
Regions	
Western	364A
Eastern	338AB
Ashanti	325AB
Brong Ahafo	267AB
Volta	237B
Central	234B

[a] Means followed by the same letter are not significantly different at $P < 0.05$

exhibited the highest P sorption index (364 mg P kg^{-1}) while the Central and Eastern regions had the lowest values (234 and 238 mg P kg^{-1} respectively).

Major soils also had distinct PSI values. The Ferralsols, with PSI of 398 mg P kg^{-1} ranked first while the Lixisols and Nitisols showed the least P sorption capacities (246 and 288 mg P kg^{-1} respectively). It should be noted that samples with PSI as high as 1000 mg P kg^{-1} were found in the Ferralsols group but were excluded from mean values computation because they were considered as outliers. However, a more comprehensive sampling effort for that category of soil is recommended to better characterize the prevailing sorption characteristics.

18.3.2 Micronutrients (Copper, Iron, Magnesium and Zinc)

Micronutrients are not part of the routine soil analysis in Ghana. Evaluation of levels of micronutrients performed in this study is based on guidelines of Lindsay and Cox (1985).

- *Copper*

Mean Cu value was 4.11 mg kg^{-1} and ranged from 2.61 for the Ferralsols to 4.88 mg kg^{-1} for the Nitisols (Table 18.5). On a regional basis, West and Central regions showed the lowest values of 2.81 and 3.60 mg kg^{-1} respectively while the highest values were obtained in the Ashanti region (5.90 mg kg^{-1}). Based on critical range of 0.2–10 mg kg^{-1} reported by Lindsay and Cox (1985), Cu might be needed in cocoa soils of Ghana. However, caution is advised and one should not overlook the fact that some Cu is brought to the system through routine application of copper-based chemical for the protection of cocoa against black pod. One may assume that, in acid soil conditions, Cu brought to the system through regular

Table 18.5 Micronutrient content of top soil (0–20 cm) in the cocoa regions in Ghana

	Cu	Fe	Mn Mg kg^{-1}	Zn
Soils				
Acrisols	4.24	218	261	2.62
Ferallsols	2.61	309	120	1.84
Lixisols	3.89	182	220	3.08
Nitisols	4.88	224	436	3.29
Pr > F	*0.23*	*0.009*	*0.08*	*0.9*
Regions				
Ashanti	5.90	159.1	319.4	3.39
Brong Ahafo	4.31	216.8	359.21	3.03
Central	3.60	158.0	219.7	3.27
Eastern	4.61	229.9	280.8	2.86
Volta	4.29	260.7	235.1	1.70
Western	2.81	259.13	171.1	2.05
Pr > F	*0.0001*	*0.0001*	*0.03*	*0.03*

application of fungicide should suffice to assure normal nutrition of cocoa regarding that element.

– *Iron and manganese*

Iron levels varied from 158 to 309 mg kg^{-1}. Ferralsols had the highest soil content and Lixisols the lowest. Manganese levels ranged from 120 to 436 mg kg^{-1} (Table 18.5) and was lowest for the Ferralsols and highest for the Nitisols. According to established guidelines (Lindsay and Cox 1985), these values are high and may in some instances induce toxicity to the crop.

– *Zinc*

Levels of zinc observed in cocoa soils range from 1.70 to 3.39 mg kg^{-1} with no statistical difference between soil groups. However, levels in soil differed in soils of the cocoa regions with lowest levels in the Volta soils while Ashanti, Brong Ahafo and Central region soils had the highest levels (Table 18.5). Based on evaluation criteria proposed by Lindsay and Cox (1985), cocoa soils of Ghana may have critical Zn levels susceptible of limiting cocoa productivity, especially when high yielding hybrids are involved.

18.3.3 Hydrological Regime and Farm Environment Association with Soil Parameters

– *Total Length of Growing Period*

Some soil parameters varied with the length of growing period (LGP). Soil pH was highest with the shortest length of growing period (LGP_3) (Table 18.6) most likely

Table 18.6 Length of growing period, farm condition and previous land use history association with exchangeable bases and pH (0–20 cm)

	K	Ca	Mg	Bsat	pHw
LGP					
LGP1	0.09	2.36	0.59	39.8	5.49
LGP2	0.11	2.54	0.69	54.1	5.47
LGP3	0.16	3.95	0.79	67.2	6.10
Pr > F	0.01	0.001	0.06	0.0009	0.001
Age					
A ($\leq$10 years)	0.13	3.14	0.71	59.2	5.71
B (11–20 years)	0.12	3.07	0.73	56.1	5.72
C ($\geq$21 years)	0.11	2.52	0.67	52.1	5.53
Pr > F	0.9	0.22	0.85	0.22	0.08
Shade					
High	0.13	3.33	0.74	59.4	5.88
Medium	0.12	3.07	0.72	58.1	5.71
Low	0.09	2.14	0.48	44.4	5.38
None	0.12	2.74	0.71	57.7	5.58
Pr > F	0.73	0.78	0.65	0.42	0.16
Preceding crop					
Cocoa	0.12	3.31	0.79	60.3	5.85
[a]Sec forest	0.13	2.87	0.74	55.8	5.57
Virgin forest	0.12	2.69	0.59	52.7	5.60
Pr > F	0.66	0.71	0.87	0.54	0.02

$LGP_1 > 330$ days; 330 days $> LGP_2 > 300$ days; 300 days $> LGP_3 > 270$ days

[a] *Sec forest* Secondary forest; *Bsat* Base saturation; *pHw* pH in water

as a result of less intense leaching of soil bases, which is supportive of the correspondingly higher level of base saturation with LGP_3 and generally higher level of base cations (K, Ca and Mg) in soils under LGP_3.

Regarding micronutrients, Mn, Cu and Zn were relatively higher in soils under LGP3, while Fe was lowest (Table 18.7).

- *Farm Environment*
  - *Age of cocoa farm*

Generally, soil bases (K, Ca, Mg) levels decreases with age of cocoa and so does base saturation, expressing a depleting effect exerted by cocoa over time on soil bases. Such base depletion is supported by the significantly higher acidity in old cocoa soil than in young cocoa farm, suggesting an acidifying effect of soil by cocoa cultivation (Table 18.6). Micronutrients did not vary significantly with age of cocoa.

Table 18.7 Length of growing period, farm condition and previous land use history association with soil micronutrients (0–20 cm)

	Cu	Fe	Mn	Zn
LGP1	3.95	235	299	2.93
LGP2	3.60	233	194	2.43
LGP3	4.88	193	321	2.95
Pr > F	*0.03*	*0.001*	*0.01*	*0.1*
Age				
A (≤10 years)	3.94	217	242	2.55
B (11–20 years)	4.27	223	252	2.64
C (≥21 years)	3.84	223	246	2.82
Pr > F	*0.49*	*0.70*	*0.83*	*0.47*
Shade				
High	4.34	241	276	2.87
Medium	4.01	214	265	2.68
Low	4.30	232	217	2.09
None	3.97	226	217	2.65
Pr > F	*0.86*	*0.3*	*0.74*	*0.95*
Preceding crop				
Cocoa	4.65	198	276	2.83
Sec forest	4.04	232	253	2.76
Virgin forest	3.50	228	214	2.40
Pr > F	*0.76*	*0.01*	*0.8*	*0.98*

$LGP_1 > 330$ days; 330 days $> LGP_2 > 300$ days; 300 days $> LGP_3 > 270$ days

- *Shade intensity*

Shade intensity did not affect significantly the various soil parameters. However, base cations and their saturation in soils were slightly higher under the highest shade regime and decreased with shade intensity reduction, exception being the no-shade category (Table 18.6). There was no apparent relationship between soil content of micronutrients and shade intensity.

- *Land use history*

Depending on the previous cropping history, soil parameters exhibited distinctive patterns (Table 18.6). Cocoa planted after cocoa resulted in lower Al in soil than when cocoa was planted after forest. Soil pH of cocoa succeeding to cocoa was less acidic than that of cocoa planted after forest. Such a trend is in line with that observed for soil Al. This result suggests that cocoa cultivation has some alleviating effect on acidity of forest soils. A direct consequence of the above is the relatively less Fe availability and lower Al saturation in soils of cocoa planted after cocoa.

There seems to be a buildup of Cu in soils of cocoa previously cropped to cocoa compared with cocoa planted on forest soils (Table 18.7). This may have a relationship with the routine spraying of copper-based fungicide in controlling cocoa black pod disease.

18.4 Conclusions and Perspectives

Recent introduction of mineral fertilizer into cocoa cultivation practices is an indication of soil fertility deterioration following inadequate soil fertility management. However, the various fertilizer formulas available are blanket in nature and their continual upgrading suggests the need for balanced and site specific fertilizer formulation for sustainable cocoa production. However, quantitative data for site specific fertilizer recommendation for crop in general and particularly for cocoa in Ghana are limited. Our soil fertility assessment study suggests that most of the soils in the cocoa regions have low fertility indices and would need adequate management for sustainable crop production. Soils in Western region, especially the Ferralsols are the most acidic, highly leached of their base cations and are the most fragile in terms of fertility. Therefore, they deserve special management geared towards replenishment of base cations status of soils. Phosphate availability is low and may represent a hindrance to cocoa productivity, especially because of the P fixing capacity of the soils. For high yielding cocoa hybrid production, it is likely that inclusion of micronutrient such as Zn in the fertilizer formulas would be beneficial (Ahenkorah 1969). Although boron and molybdenum were not analyzed in the current soil fertility assessment, they are to be considered in balanced fertilizer formulation for cocoa as pointed out by previous studies (Assomaning and Kwakwa 1967).

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