Chapter

Fertilizer Use Issues for Smallholder Agriculture in Tropical Africa

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Abstract

Fertilizer is an essential input for wide-scale sustainable intensification of crop productivity in tropical Africa, but its use by smallholders is often financially constrained. Four fertilizer use issues are addressed. Smallholders need high net returns from their investments, with acceptable risk, which can be achieved with good crop-nutrient-rate choices made in consideration of the farmer's financial and agronomic context. Soil acidification, which is affected by crop N supply, is best managed with the use of slightly more acidifying but less costly common N fertilizer, e.g., urea, coupled with lime use compared with the use of more costly but less acidifying N fertilizer such as calcium ammonium nitrate. This chapter addresses the feasibility of tailored fertilizer blends for maximizing farmer profit with respect to the nutrient supply cost, the need for flexibility in nutrient application according to the farmer's context, and the weak justification for tailoring blends based on soil test results. The use of a well-formulated blends is justified in some cases, e.g., for some crops in Rwanda, but the supply of blends does not justify restricting the supply of common fertilizers. Farmers need to be aware that unregulated nontraditional products very often fail to provide the claimed benefits. Fertilizer use, sometimes with timely lime application, can be highly profitable with modest risk with good crop-nutrient-rate choices, adequate free-market fertilizer supply, and avoiding products with unsubstantiated claims.

Keywords: Africa, smallholder, fertilizer, profit, blends, soil acidity, non-traditional products

1. Introduction

Fertilizer use is essential for widespread sustainable increases in crop productivity and for the preservation of the cropland resource base in tropical Africa. Smallholder farmers in tropical Africa generally have severe financial constraints and need high returns to justify an investment, often >100% within a year [1]. Risk needs to be low given the vulnerability of their livelihoods to failed investments. Fertilizer use can have a high probability of high profit with well-informed crop-nutrient-rate choices but also with efficient input supply, favorable credit terms, subsidies, and efficient marketing of the commodity produced [2–4]. The objective of this chapter was to explore four issues affecting the profit potential of fertilizer use by financially constrained smallholder farmers: (1) the choice of fertilizer use options with the greatest potential return on investment, (2) the choice of N source and management of soil acidification, (3) the use of tailored fertilizer blends as alternatives to common straight fertilizers, and (4) the alternative nontraditional products for managing soil productivity. The implications for farm profitability are fundamental to the discussion of these issues.

2. Fertilizer use for maximization of the farmer's profit

Smallholder cropping systems are typically diverse, and each crop or intercrop has some level of profit potential for each nutrient that might be applied [2, 3, 5–13]. Crop-nutrient response functions typically have a diminishing profit-to-cost ratio as the nutrient rate approaches the agronomic optimum. A financially constrained farmer maximizes net returns through optimized choice of crop-nutrient-rate options (**Figure 1**; [4]). In contrast, when fertilizer use is not financially constrained, the profit-oriented farmer targets to apply at the rate at which net returns per hectare are maximized. Fertilizer use decisions can be made by integrating crop-nutrient response functions using linear optimization through computer-based and simple paper decision tools that have been developed for 73 recommendation domains across 15 nations of tropical Africa by the project Optimizing Fertilizer Recommendations in Africa [2, 3, 14].

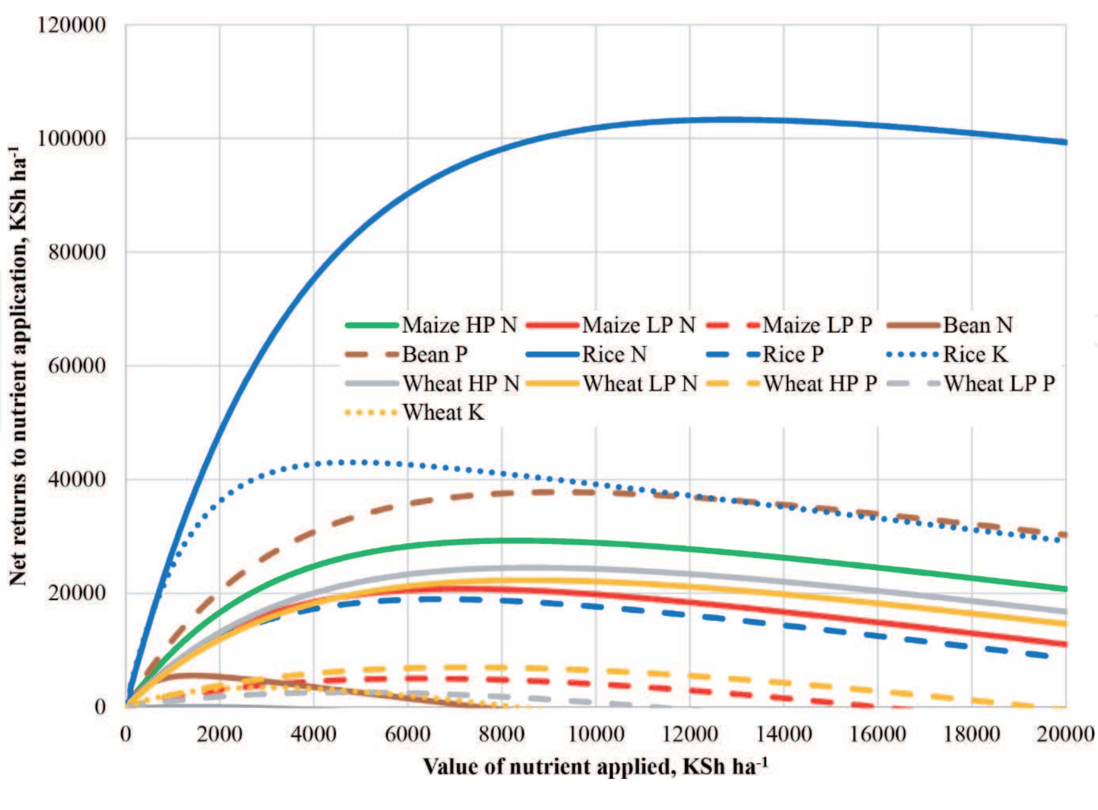

Figure 1.
Net returns in Kenyan shillings (KSh) to investment in nutrient application vary with crop-nutrient-rate choices, exemplified for Central Kenya with fertilizer use costs and on farm commodity values typical in 2016 [4].

3. Management of soil acidification and nitrogen sources

Supply of nitrogen to cropland typically contributes to soil acidification whether the N is supplied through fertilizer, organic materials, biological fixation of atmospheric N, or wet and dry deposition of atmospheric NH_4-N [15]. Soil acidification also occurs with NH_4^+ uptake by plants with subsequent release of cations, mostly H^+. Soil acidification is greater if NO_3^--N is leached from the soil rather than recovered by plants. Soil acidification associated with N sources can be slowed by avoiding excessive application of N and leaching of NO_3^--N and by the use of less acidifying but more costly NO_3^--N fertilizers [16]. Very often, it is most economical to use relatively less expensive but more acidifying NH_4^+-N fertilizers and occasionally amend the soil with lime application rather than using less acidifying fertilizers.

Soil acidification concerns are important in Kenya, for example, especially in some high elevation and high yield potential areas (**Figure 2**). The promoted N fertilizer for these areas is calcium ammonium nitrate (CAN) rather than urea. The chemical composition of CAN varies, but CAN of 27% N contains about 13.5% each of NH_4^+-N and NO_3^--N, and calcium carbonate or calcium-magnesium carbonate (dolomite) may be added to give the fertilizer about 20% calcium carbonate equivalent (CCE). The acidification effect of ammonium nitrate and urea is 3.65 kg CCE for each kg of N applied. If the CCE of CAN is neutralized in the soil, it reduces the net acidification effect of CAN-N by about 22% to about 2.85 kg CCE kg^{-1} N. Therefore, urea is about 28% more acidifying per kg of N compared with CAN. Calcium is supplied by CAN but cannot be credited with economic value to farmers if the yield response to CA is not profitable.

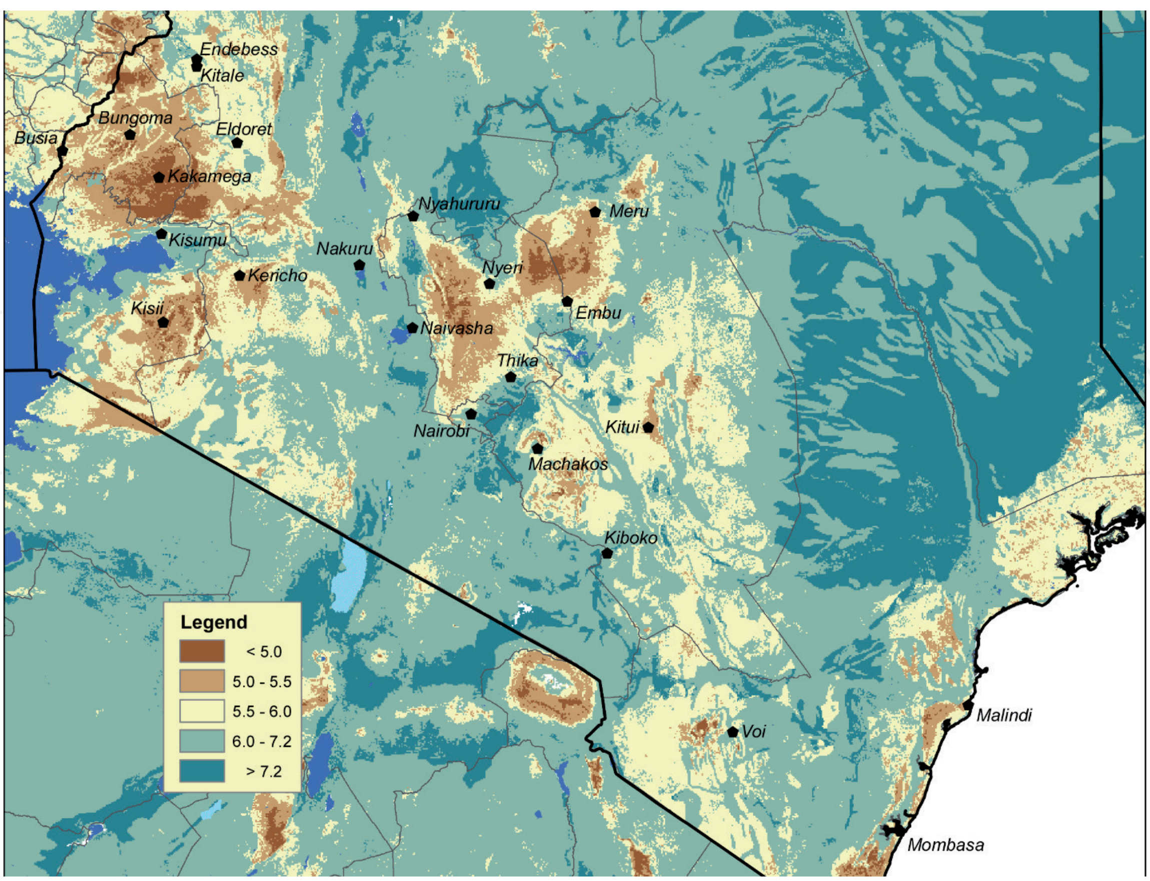

Figure 2.
Soil pH distribution across Kenya determined using AfSIS data.

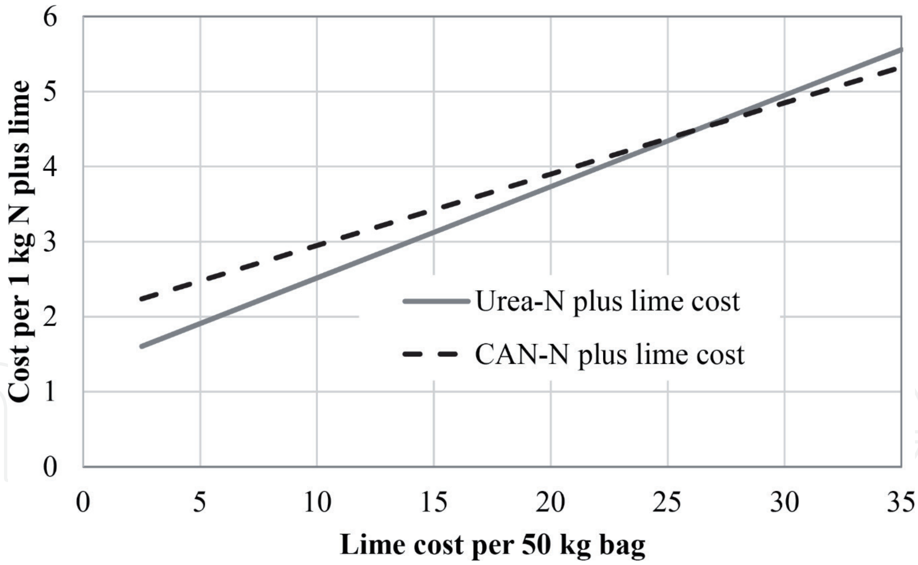

Figure 3.
Comparison of the retail costs of N supply using urea and calcium ammonium nitrate, plus the cost of agricultural lime for neutralizing the fertilizer acidification effects (US$), based on common fertilizer and lime costs in Kenya in 2016.

The farm-level 2015 costs in western Kenya were 1.3 US$ kg^{-1} for urea-N, 2.0 $ kg^{-1} for CAN-N, and 0.17 $ kg^{-1} for effective CCE of lime. The retail cost of fertilizer N plus lime to neutralize the N effect on soil acidity was $1.30 + 0.166 × $ 3.65 = $1.91 kg^{-1} for urea-N and $2.00 + 0.166 * $2.85 = $2.47 kg^{-1} for CAN-N and 30% more costly for the CAN compared with urea option. The CAN compared with the urea option remains less profitable at these fertilizer prices if the cost for effective CEC of lime is <0.90 $ kg^{-1} (**Figure 3**).

4. Blended and compound fertilizers

Blended and compound fertilizers are mixtures of common or straight fertilizers. Blended fertilizers are mixtures of common fertilizers which are distinguishable in the mix. Compound fertilizers are formulated by re-granulating the component common fertilizers to have some of each fertilizer in each granule. Hereafter, blended and compound fertilizers are referred to as blends. Common fertilizers often used in dry blends include urea, triple super phosphate (TSP), diammonium phosphate (DAP), and potassium chloride (KCl).

The flexibility in nutrient application with common fertilizers is often important for profit optimization. For example, cereal yield response to N followed by P often has more profit potential than the application of K, secondary nutrients, and micronutrients. The application of several nutrients in a blend can result in increased yield compared to the application of fewer nutrients with the farmer's chosen combination of common fertilizers such as for wheat and maize production in Rwanda, but the profit potential is more often greater with common fertilizers [5, 7, 12, 17]. Blending adds to the cost of nutrient supply, and blends often contain one or more nutrients that have low or no profit potential for the farmer. For example, maize (*Zea mays* L.) yield responses to K included 57% of 164 cases in tropical Africa with increases and 18% with decreases >0.1 Mg ha^{-1} [18]. This indicates an NPK blend may be advantageous in some cases compared to common fertilizers but there are many cases where K use needs to be highly selective. Unfortunately, governmental policy decisions in some countries limit farmer access to some potentially valuable common fertilizers such as TSP, DAP, and KCl. Three concerns of enabling supply of blends while restricting the supply of common fertilizers are addressed here. (1) Claims of profit increases for farmers, with less soil acidification, with the use of blends compared with the judicious use of common fertilizers, are often not true. (2) Tailoring of blends for smallholders in Africa should not be based on soil test information which is scarce and likely to be highly variable across a farm but especially due to the weak basis for interpreting soil test results relative to crop yield response to applied nutrients [19]. (3) Smallholder farmers generally need high return on investment with little risk of failed returns to justify an investment.

5. Blended and compound fertilizers: yield and soil acidification

The acidifying effect of blends depends on their ingredients. Common fertilizers that are generally available on the world market at very competitive prices and with relatively high nutrient content are commonly used to produce blends. The nutrient contents of blends need to be reported, but the constituent fertilizers commonly do not need to be reported. However, a dry NPK blend is expected to contain urea, DAP or mono-ammonium phosphate, and KCl or potassium sulfate. Applying basic algebra for a 17-17-17, for example, it could be composed of 22.5, 37.0, 28.3, and 12.2% of urea, DAP, KCl, and bulking material, respectively, but it could not be 37.0, 37.0, and 28.3% of urea, TSP, and KCl as these total to >100%. The soil acidification effect of the blend depends on the constituent fertilizers. The acidification effect of the urea-DAP-KCl blend could be only slightly reduced by replacing some of the DAP with TSP since TSP is a non-acidifying P source for acid soils or using lime as the 12.2% of bulk material. Therefore, a fertilizer user should not expect a fertilizer blend to be a much less acidifying means for nutrient application compared with judicious application of common fertilizers.

6. Tailoring of blends based on soil test information

Soil test values vary considerably within and across smallholder farming operations with soil texture, depth, and pH generally stronger determinants of crop yield and yield response to nutrients than are soil test results for nutrient availability [20, 21]. However, the probability of maize yield response to N and P is high for agricultural soils not having severe edaphic and other abiotic and biotic constraints. Of 727 N and 672 P yield response functions determined from field maize trials in tropical Africa, yield increases were >0.1 Mg ha^{-1} for 87% of the N functions and 69% of the P functions [18].

Interpretation of soil test results for the estimation of the probability and magnitude of profitable yield response to applied nutrients is generally weak globally for most secondary and micronutrients, with Zn being a possible exception, even where nutrient management is strongly based on field research results. Soil test information has a low or negligible predictive value for crop yield response to applied nutrients in tropical Africa [19]. Soil S tests have been less indicative of crop yield response to S than the use of soil organic matter content and soil texture [22, 23]. Situation-specific interpretations of soil test results for micronutrients have been useful but are unconfirmed for extensive use across geographic and climatic conditions [24]. Hot water extraction of B has been useful in predicting alfalfa yield response to B, but prediction is improved by consideration of soil texture [25]. Different nutrient extraction procedures for soil tests require different interpretations. Mehlich-3 extraction [26] is increasingly used for good reasons but does not correlate well with DTPA extraction for most micronutrients with R^2 values of

0.88 and 0.90 for Zn; 0.42 and 0.63 for Fe; 0.50 and 0.88 for Cu; 0.50 for B; and 0.05 for Mn [27–30]. Therefore, interpretation of Mehlich-3 extraction results is appropriate where crop yield response has been calibrated directly with Mehlich-3 data.

Interpretation of soil test results in terms of probability of profitable yield response to an applied nutrient can be expected to be weak in tropical Africa because crop yield and yield response to inputs in the tropics typically encounter numerous unmitigated constraints that are periodically more constraining than a nutrient deficiency [31, 32]. Each of these constraints not only limits yield but also crop yield response to attempts to mitigate another constraint and ability to predict response. Wendt and Rijpma [33] did not find a relationship between soil test information and crop yield response to applied S, Zn, and B in Malawi for individual fields. Kaizzi et al. [34, 35] did not find a soil test relationship for maize and sorghum yield response to N, P, and K in Uganda. In the analysis of >1100 cases of crop yield response linked to soil test information, Mehlich-3 extracted P and K accounted for <1% of the variation in yield response to application of these nutrients [19]. With more research, interpretation of soil test results for tropical Africa is expected to improve, but soil test results do not provide a practical basis for the tailoring of fertilizer blends in tropical Africa at this time.

7. Blends and the farmer's financial context

The greatest profit/cost potential is likely to be with the application of one or two most limiting nutrients, often N and P for non-legumes and P or P plus another nutrient for legumes [5, 7, 12, 17]. Positive synergistic effects of applying the two most limiting nutrients occur infrequently but tend to account for relatively little yield response compared with the additive effects of individual nutrients e.g., [6, 8–11, 17, 34–37]. Therefore the highest profit/cost ratio can generally be achieved by at least partly alleviating the most limiting nutrient deficiency constraint followed by the second most limiting deficiency.

Farmer profit from fertilizer use may be maximized in some situations through the use of relatively more costly blends compared with common fertilizers such as cited above for wheat and maize in Rwanda [5, 17]. The blends may then at least partly meet the needs for those two most limiting nutrients as well, commonly applied near planting time. Blends should not contain nutrients with inadequately verified yield response unless the added cost to the farmer is minimal as any money that a financially constrained farmer uses for relatively costly fertilizer implies less money available for common fertilizers that may have higher profit potential.

8. Nontraditional materials for crop production

Small bottles of nutrients or other solutions or suspensions are commonly sold in agricultural input shops in Africa with claims that use of small amounts can substitute partly or fully for fertilizer. The price per small bottle, even with a wide profit margin, compared to the price of a 50-kg bag of fertilizer is small, but the nutrient quantity is also very small, and the cost per kg of nutrient may be extremely high. These may contain micronutrients, often as low solubility oxides and carbonates, but the form and solubility are usually not specified. Some such products are sometimes vaguely referred to as bio-fertilizers and bio-stimulants and are mostly unregulated. These may have claims of increased crop growth, yield, or tolerance to insect pests, diseases, or drought or more efficient nutrient cycling. The Compendium of Research Reports on Use of Non-Traditional Materials for Crop Production [38] addresses a fraction of such products that have been marketed in the USA, most of which are no longer available or occur under a different name. Others have been found to be effective for specific situations and have an enduring history of use. No such compendium exists for tropical Africa.

Bio-fertilizers may contain microbes or microbial metabolites claimed to fix atmospheric N, convert insoluble P into soluble forms, or stimulate plant growth. Some products such as *Rhizobium* inoculums for increased symbiotic N fixation with legumes can be very effective in the right situations [39]. A product may contain other N-fixing microbes such as *Azospirillum* and *Azotobacter* which may be effective if they can successfully compete with indigenous *Azospirillum* and *Azotobacter* and the rest of the soil microbial community. The well-targeted use of *Bacillus* and *Pseudomonas* microbes can improve soil P availability but may not compete effectively with the indigenous microbial community [40]. The value of vascular arbuscular mycorrhizal fungi, especially to P and Zn uptake, has been long known, but inoculation very often fails to improve mycorrhizal effectiveness. Such products tend to broadly marketed as effective for all situations, but their use needs to be narrowly targeted to specific conditions. Handling, storage, and application timing and method affect bio-fertilizer effectiveness [41, 42].

Bio-stimulates often are of unknown contents but often contain hormones or humic acid. Hormone application can be effective for specific crops in specific situations, but use across a broad spectrum of production situations is unlikely to be effective for well-adapted crop varieties grown on at least moderately good agricultural soil. Humic acid is important to plant growth but is already abundant in soil. A soil of 3% organic matter may have 1–1.5 Mg ha^{-1} of humic acid in the surface 20-cm soil depth, and adding humic acid at a few kg ha^{-1} has a low probability of increasing yield [35].

9. Conclusion

Fertilizer use is essential for wide-scale sustainable improvement of crop productivity in tropical Africa even though smallholder farmers commonly are severely constrained financially. They require high profit/cost ratios of their investments, with acceptable risk, to gradually reduce the limitations of poverty. Fertilizer use can be highly profitable with good crop-nutrient-rate choices made in consideration of the farmer's financial and agronomic context. Maximizing the profit/cost ratio usually requires adequate access to common fertilizers. Soil acidification is a concern and is a partly an unavoidable consequence of N supply to crops. The most cost-effective means for management of soil acidification often involve avoiding excessive N application and the use of slightly more acidifying but less costly common NH_4^+-N fertilizers coupled with lime use compared with NO_3^--N fertilizers and less lime use. The feasibility of tailored blends has been addressed in consideration of the cost of nutrient supply, the need for flexibility in fertilizer use for maximization of farmer profit, and the weakness of tailoring blends based on soil test results in tropical Africa. However, justification for blends for exceptions such as for wheat and maize in Rwanda should not restrict the supply of common fertilizers. Farmers need to be aware that unregulated products sold in small bottles or packets very often fail to provide the claimed benefits. Fertilizer use, sometimes with timely lime application, can be highly profitable with modest risk if based on good crop-nutrient-rate choices, with adequate fertilizer supply and avoidance of products with unconfirmed claims.

Abbreviations

CAN	calcium ammonium nitrate
CCE	calcium carbonate equivalent
DAP	diammonium phosphate
DTPA	diethylenetriaminepentaacetic acid
TSP	triple super phosphate

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