

Soil SMaRT

A CONCEPTUAL FRAMEWORK FOR
DELIVERING IMPROVED FERTILIZERS TO
SMALLHOLDER FARMERS IN AFRICA

October 2017



INTERNATIONAL FERTILIZER DEVELOPMENT CENTER
PO BOX 2040 | MUSCLE SHOALS, AL 35662 | USA

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A Conceptual Framework for Delivering Improved Fertilizers to Smallholder Farmers in Africa

Status of Fertilizer Use in Sub-Saharan Africa

Fertilizer use in sub-Saharan Africa (SSA) is low, averaging 16 kilograms (kg) fertilizer per hectare (ha) of arable land. This does not imply that the average farmer uses 16 kg/ha. The reality is that many farmers do not use any fertilizers, while commercial and smallholder farmers that do apply fertilizers use much higher rates. While several factors, including accessibility, cost, and lack of output markets, constrain farmers' use of fertilizer, a major problem facing smallholders is the lack of diversity in fertilizer products to address soil- and crop-specific demands.

The main fertilizers available to smallholder farmers are what are referred to as “commodity fertilizers,” including diammonium phosphate (DAP), urea, calcium ammonium nitrate (CAN), 15:15:15 or similar NPKs, and occasionally NPKS products such as 10:20:10+6S or 23:21:0+4S. In many African countries, farmers have access to only two or three commodity fertilizers, making it difficult to address crop-specific demands or address secondary and micronutrient deficiencies. Lime products are often not available and seldom used when they are. In some cases, fertilizers are not available at the appropriate time due logistical and procurement problems, resulting in late application. As a result, fertilizer use efficiencies are less than half of what is achieved in agriculturally developed countries. Poor response and high costs discourage fertilizer use.

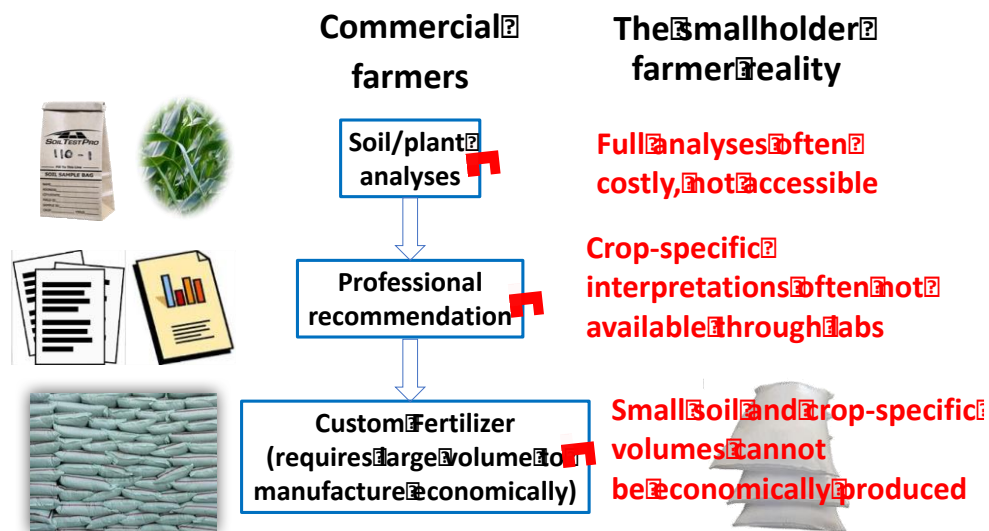
Relative to much of the world, African soils are poor, with most not having not been enriched by recent geological activity such as glaciation, volcanic processes, mountain outwash, or acid rain, which until recently provided considerable quantities of S in industrialized countries. As a result, NPK fertilizers seldom address the suite of nutrient deficiencies present and, while they usually improve yields, do not result in optimal nutrient response. Vast tracts of secondary and micronutrient deficiencies (primarily sulfur [S], zinc [Zn], and boron [B]) and soil acidity constraints have been identified through various mapping initiatives, and superior responses to balanced fertilizers that supplement NPKs with appropriate secondary and micronutrients have been observed in several countries. Fertilizer blending companies, primarily serving commercial farmers, now exist throughout the continent, but their products are not available to most smallholders, who often are impeded by cost considerations, lack of awareness and access, and subsidies on commodity fertilizers, which are persuasive in farmer purchasing decisions. A few commercially available balanced fertilizer compounds exist, but these are generally not targeted to soils or the food crops grown by smallholders.

Delivering balanced fertilizers to smallholder farmers is a high development priority. Obtaining better fertilizer response is necessary to improve stagnant productivity (yield per hectare) and for addressing human nutrition and farm income objectives. In this paper, we lay out a conceptual framework for delivering improved fertilizers to smallholder farmers at a large scale, primarily in the African context.

The Smallholder Farmer Context

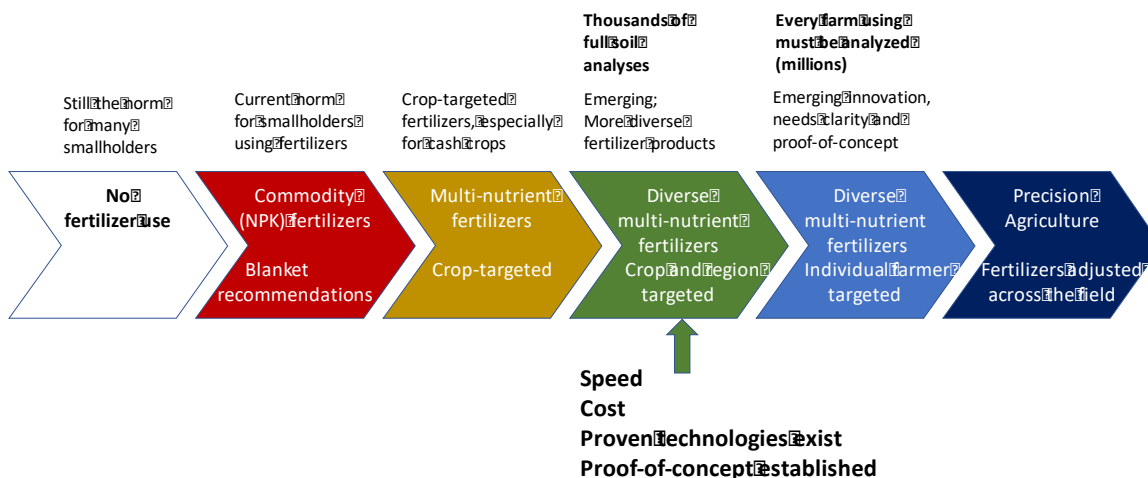
Addressing smallholder farmer fertilizer requirements differs markedly from addressing those of large commercial farmers. Commercial farmers are willing to pay for, and generally have access to, full soil and plant tissue analysis, which aids in diagnosing likely deficiencies. After getting a crop-specific recommendation for a desired yield target, they purchase in volumes that can reasonably be produced by a commercial blender or specialty fertilizer supplier—often more than 5 metric tons (mt). They also have equipment that can efficiently apply fertilizers at variable rates that match recommendations.

The smallholder reality is very different. Most smallholders cannot access full soil analyses and, if able, are unlikely to invest in them due to the expense. Having small land holdings and often multiple crops requiring different fertilizer and lime recommendations, it then becomes impossible to access the correct fertilizer, as a blender cannot economically produce anything less than several metric tons. The fertilizers available from agro-dealers are most likely NP and NPK products of fixed nutrient ratios, so there is usually no opportunity to apply other nutrients or adjust the NPK ratio to fit the soil analysis and crop. Even when additional nutrients are available, applying them in the correct dosage poses challenges. Many micronutrients are required at less than 1 kg/ha, which farmers cannot distribute evenly. For commercial farmers, these are usually incorporated into NPK granular fertilizers to ensure even distribution. Overapplication can induce toxicities (especially for B) and can cause other deficiencies. While some have proposed inexpensive field soil test kits for soil analysis based on wet chemistry and, more recently, infrared spectroscopy, these generally measure only the soil pH and macronutrients. Challenges exist in converting kit analyses into crop-specific recommendations, even for the few analyses the kits perform. Kits are also a slow extension tool, as they require individual farmer field analysis. While soil test kits are still in development conceptually, yield improvements based on some kit analyses have yet to be validated.



Phases in Fertilizer Evolution

The phases in fertilizer evolution in the sub-Saharan Africa context are represented below. Many smallholders still apply no fertilizers. The first major advance in smallholder fertilizer use was the availability of macronutrient (N, NP, and NPK) commodity fertilizers. These are available in most countries. Crop-specific fertilizers, primarily available for cash crops, have also entered the market, targeted to such commodities as cotton, cocoa, coffee, and tea and increasingly food crops, including cereals and potatoes. These formulations are broadly based on the specific nutrient demands of the crop and are for the most part developed without respect to varying soil conditions. They often contain secondary and micronutrients to which specific crops generally respond.



Further diversification of available fertilizers is based on knowledge of soil deficiencies and, as such, requires soil and/or plant tissue analyses at regional or country scales. Due to the importance of secondary and micronutrient deficiencies in SSA, analytical capabilities need to go beyond simple NPK analyses.

A further level of targeting is at the individual farm level. While potentially useful, this level of targeting is currently outside the means of most smallholder farmers due to cost and accessibility of analyses. Promising technologies are being developed to address these constraints. These include soil test kits, which can analyze for pH, N, P, and K, and sometimes S and organic C. Such information could conceivably combined with information of other nutrient deficiencies in the region to better target a recommendation. Spectral soil methods may also be of use due to cost reductions and speed, and research is underway to improve calibrations with nutrient uptake and crop response. Spectral methods are very accurate for plant tissue analysis, which may provide more reliable information regarding certain deficiencies. Kits may also be designed to aid in specific choices available to farmers to increase the returns on their fertilizer investment: Should lime be applied? Do I need a topdress application? Should I include sulfur or potassium? All of these approaches hold promise, but whatever the approach, a “proof of concept” needs to be demonstrated and the market implications in terms of product delivery appreciated—delivering diverse products to farmers and farmer training on applying varying rates for different nutrients. *Whatever the field-specific methodology, it must demonstrate that the recommendations coming from it offer a substantial improvement over currently available blanket fertilizer recommendations for most users.* A poor recommendation has implications for a farmer’s livelihood (not to mention, project reputation), so validation of an approach should be established before scaling. Research of these pathways is encouraged, taking into account the above factors.

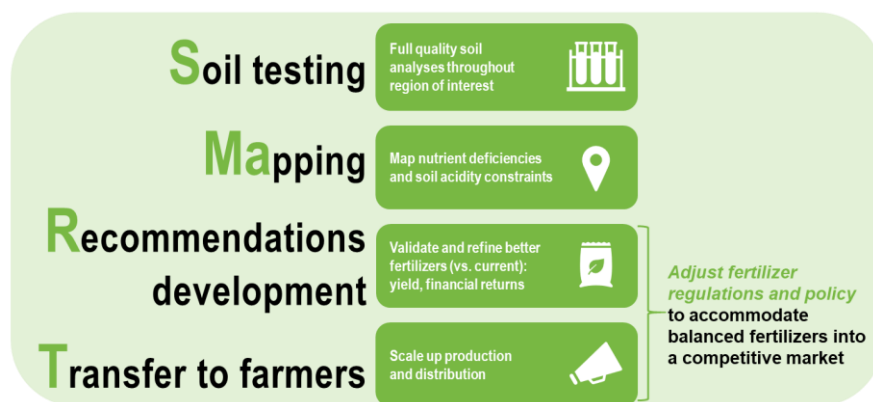
For these reasons, we consider that developing crop- and region-specific fertilizer recommendations to be the most promising next phase in fertilizer evolution in SSA. It is relatively rapid and cost-effective. It is based on currently available technologies, and its implementation will likely accelerate as technologies evolve. Developing this approach has its own challenges and requires coordination of stakeholders across the fertilizer value chain. The SMaRT concept, explained below, provides a framework for activities and stakeholder coordination.

The SMaRT Approach

SMaRT is an acronym for Soil testing, Mapping, Recommendations development, and Transfer to farmers. The concept behind SMaRT is to get better fertilizers to farmers for a given crop and region that substantially and sustainably outperform fertilizers currently used by farmers. Sustainability is addressed by using “balanced” fertilizers, which have a balance of macro, secondary, and micronutrients that address predominant nutrient deficiencies. Lime may be part of a SMaRT recommendations when it is available and required. Many aspects of the SMaRT approach have been implemented in various countries. Where quality soil analyses, mapping, and/or crop response data exist, they should be reviewed and collated to avoid duplication of effort. The SMaRT concept requires that a facilitating environment exist or be developed, in terms of fertilizer regulations and fertilizer policy.

From soil analysis to smallholder fertilizer use:

The SMaRT Approach



The SMaRT concept begins with **soil sampling**. A minimum sampling density of 25 km² (approximately 5 x 5 km, not necessarily on a grid) of cropped land was sufficient to identify likely nutrient deficiencies and soil acidity constraints in Rwanda and Burundi, but sampling methods based on underlying soil classification maps, topography, geology, climate, and other variables will be more efficient. A sampling depth of 0-20 cm is desirable, and deeper samples (20-50 cm) can provide additional information on constraints such as subsoil acidity, subsoil nutrients such as S or Cl, and soil texture and other physical impediments to crop growth. Samples receive a full analysis for all essential nutrients, soil pH, electrical conductivity, organic C, total N, and soil texture from a pre-evaluated qualified laboratory, using recognized procedures. Other factors that might be considered include exchangeable acidity and phosphorus sorption capacity. While many

procedures are “recognized” (there are at least three procedures commonly employed for most nutrients), harmonization is desirable to facilitate interpretation of results, as the amounts of nutrients extracted and consequent interpretation are dependent upon the procedure used. Some of these analyses may be performed spectrally if good spectral calibrations or relationships to yield or nutrient uptake have been achieved.

In the **mapping** step, analytical results are mapped. Nutrient deficiency and soil acidity maps are not the same as soil classification maps, which are already available at different scales. The purpose of the mapping is to show areas that have likely nutrient and soil pH constraints, as well as toxicities when they exist, that need to be corrected. Maps may also indicate other restrictions to crop growth, such as shallowness of soils, likely nutrient toxicities, and salinity. Mapping may concentrate on specific zones of production, for example, a rice lowland, an area of cocoa-intensive production, or a maize belt.

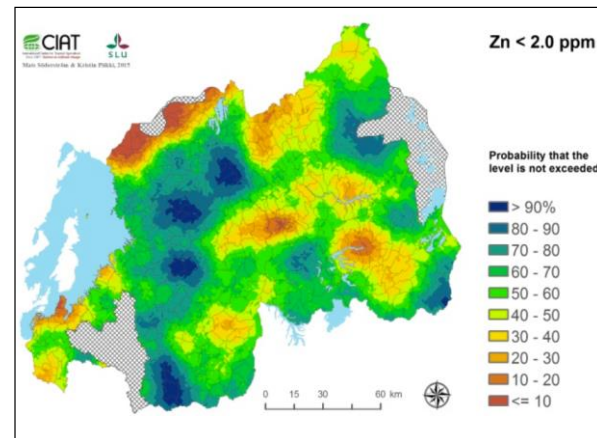
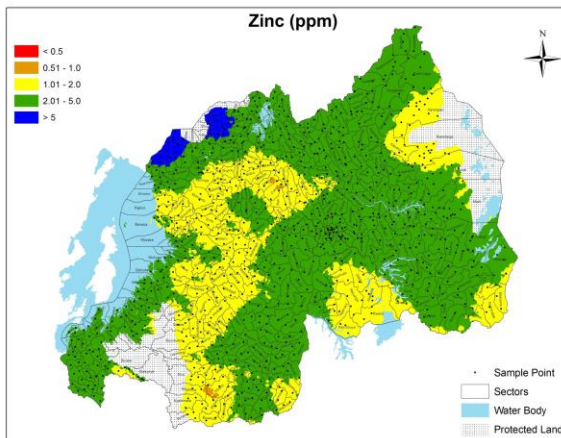
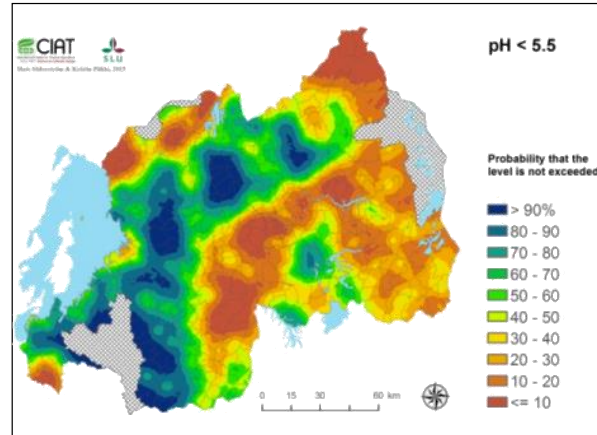
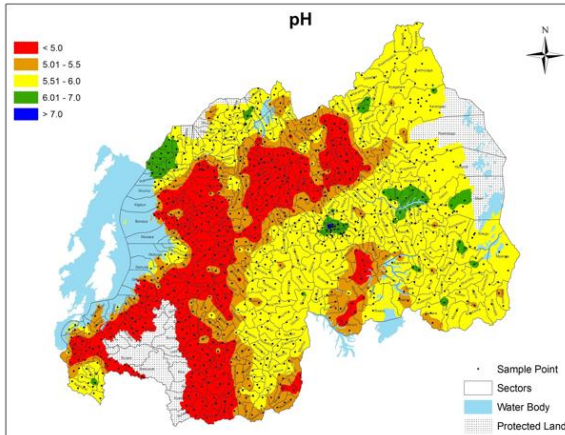
Mapping is a worthy project output in itself. As a public good, it is available to both the public sector and to fertilizer companies. Fertilizer companies can use maps to target their products, based on their best interpretation of results, to crop-specific needs. Maps are also very influential in informing policy and agricultural research priorities, which may not have taken into account the extent of constraints other than N, P, and K. Maps can spark urgency develop and support balanced fertilizers.

Quality of Soil Analyses Required for Mapping

While complete quality soil analysis is more expensive, it is not an area for compromise, particularly when invested as a public service. The largest expense is usually not in soil sample analysis, but in sample collection and transportation to a qualified laboratory. Poor quality soil analysis, either due to the methods themselves or to the analytical laboratory, will not provide a good guide as to which nutrient deficiencies and acidity constraints predominate or their spatial distribution.

While less accurate but faster, less expensive methods may have a role, methods of complete soil and/or leaf analyses that are well-correlated with crop response are necessary for mapping, particularly in the African context, where the likelihood of response to secondary and micronutrients and the correct type of lime (either calcitic or dolomitic) is high. Spectral analysis may replace some wet soil methods for several determinations, including soil pH, total N, organic C, and P-fixation capacity, and is well-calibrated for most nutrients in plant tissue.

Maps may take on various forms according to user requirements. In terms of nutrient maps, one may wish to represent the range of nutrient values or, if a critical nutrient level is known, the probability that the soil analytical value is below the critical value. The first type of map may assist in addressing specific crop demands, as different crops have different nutrient requirements. A probability map can assist a fertilizer company in determining the likelihood of response to a given nutrient-crop combination in a specific geographical region.



Crop Nutrition Laboratories, Nairobi

M. Söderström & K. Piikki, CIAT

Maps, when combined with other information, can be used for purposes such as developing yield targets or assessing crop suitability. This can inform fertilizer use and policy decisions.

The **recommendations development** step is concerned with developing fertilizer recommendations that address predominant constraints. A recommendation is both a fertilizer formula and an application rate. Fertilizer formulations (e.g., 12:24:12+6S+0.5Zn+0.2B) indicate the percentages of nutrients in a blend or compound. By multiplying the rate of application of the fertilizer (in kg/ha), the amounts of nutrients applied per hectare can be calculated. Different yield targets may be addressed by different fertilizer application rates.

Fertilizers should be assessed within the guidelines contained in the 4R Nutrient Stewardship framework promoted by the fertilizer industry: the right source of fertilizer at the right rate, time and placement. The 4R framework is implemented in the context of the crop grown, soil type and weather, among other factors. Other good agricultural practices, such as timely planting and weeding, should also be employed.

During the development of recommendations, several “best-bet” fertilizers may be tested. A best bet is not a recommendation, but becomes a recommendation once its yield and economic superiority have been established through on-farm trials. A best-bet trial involves one or more best-bet alternatives, the current fertilizer, and a non-fertilized control. The control plot is essential for economic assessment.

In developing recommendations, a starting point is to understand the nutrients removed in the harvested products. For a given yield target, estimates of nutrient extraction from both crop and stover are available for many crops.

For the macronutrients N and P, one generally wants to apply sufficient amounts to offset extraction, even though a soil may have moderate available N and P levels, so that the developed fertilizer will be able to sustain a yield target without annual adjustment. Therefore, N and P rates are generally determined based on crop extraction, unless for exceptional areas where high N and/or P levels are observed that can sustain production for several years. Such soils have occasionally been found in high organic matter volcanic or inland valley soils.

Phosphorus application rates may also consider the P fixing potential of the soil. For potassium, while extraction rates are high for many crops, return of the nutrient to the soil from crop residue can also be high if crop residue is not immediately removed.

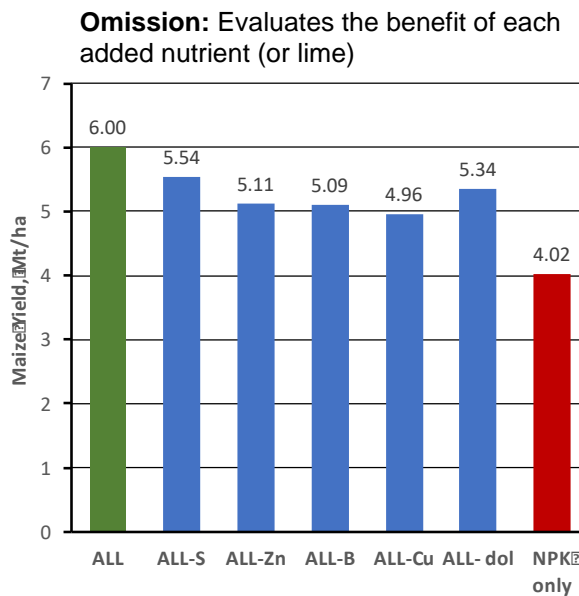
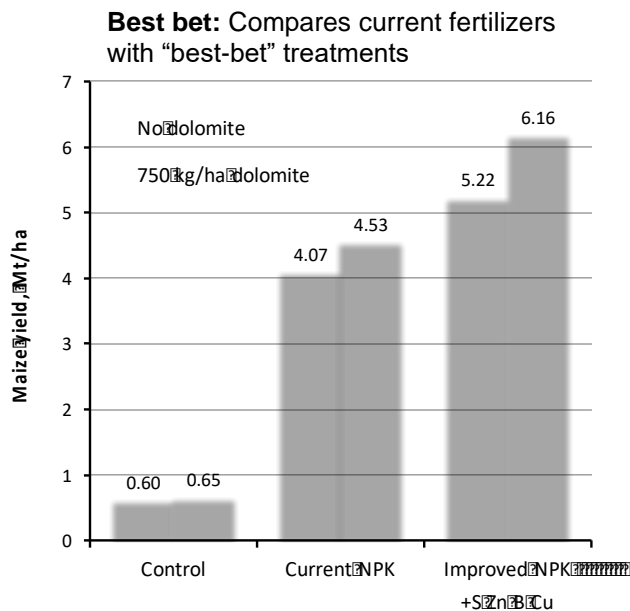
Some soils can also have a high K supplying capacity that will sustain production for decades; in such circumstances, minimal or no K may be required. Most soils can provide some K, and for many crops including maize, tables have been developed for K application rates based on soil analysis values and yield targets. Micronutrients, when incorporated or coated onto granular fertilizers, need only be applied at about twice the crop removal rate to account for leaching (boron) or fixation (common with zinc and copper). Some crops are very sensitive to specific nutrient deficiencies, whereas others are sensitive to overapplication. A knowledge of specific crop demands and sensitivities helps guide best-bet formulations.

Nutrient omission trials can be conducted in conjunction with best-bet trials. While soil testing is often a good guide for developing best-bet formulations, it also has its limitations. Some nutrients cannot be accurately predicted with a soil test, and unexpected responses often occur.

Nutrient omission trials provide more definitive data about which nutrients belong in a formula and can be used to evaluate the economic impact of each nutrient and lime on yields. Leaf tissue analysis can also provide evidence as to whether all nutrient needs are being addressed and is often a reliable way of detecting deficiencies.

What is a successful recommendation?

- Addresses identified nutrient deficiencies.
- Can sustain yield targets for the long term.
- Must consider crop removal, not just immediate soil conditions.
- While not the perfect formulation, is a substantially better formulation for most farmers in terms of yield increase and economic returns.
- Is marketable in terms of cost and production volumes to target farmers.



For trials to have broad applicability, they are best done on-farm in widely dispersed areas. On-station sites are usually avoided, as they may have been subjected to other fertility trials that leave residual effects, or may have been better managed historically, and thus may not reflect on-farm realities. On-farm response data provides the economic justification for a fertilizer formulation, which informs fertilizer providers if they truly have a superior product. These trials may also provide the economic justification for changing fertilizers offered under subsidy programs. At least 30 sites in a region with soil and climatic similarities are required to provide sufficient statistical resolution to validate response.

Some may wish to forgo trial work for various reasons. If available NPK formulations or recommendations clearly do not match crop demands, one may be able to bring to market a better product and use a season’s worth of on-farm demonstrations for farmer promotion, even without soil analyses. Some specialty fertilizers, such as controlled-release nutrient products, may perform better than standard NPKs, regardless of soil fertility. Some fertilizer companies simply formulate based on crop demand, irrespective of soil constraints. All these approaches can bring better products to the market in many circumstances. Nevertheless, having maps of soil constraints can guide companies to produce better products, particularly in a competitive market. Any trial work, when conducted in collaboration with national governments, produces data that forms the economic basis for changes in recommendations and can be a valuable knowledge contribution to subsidy programs.

Interpretation of Results

Professional soil analysis interpretation is required to generate best-bet treatments. Interpretation in the context of smallholder fertilizer recommendations is not a straightforward process and will be context-specific. Recommendations must consider the crop grown, the yield target, the current farmer application rate and/or subsidy provision, and a crop-specific interpretation of soil analytical results. It is desirable to keep the application rate within subsidy guidelines or practically affordable rates, though this is not always possible, particularly if K or S is required and is not in a current formulation such as DAP, as these added nutrients often increase fertilizer volume. Farmers can adjust rates based on yield targets or financial means. Micronutrients can be added by

only slightly increasing fertilizer volume, such that their addition need not affect fertilizer application rates.

Different analytical laboratories have different interpretive methods. For example, some laboratories will use co-factors such as soil pH, soil texture, organic matter concentration, and different nutrient ratios (e.g., C/N ratio or ratio of K to other bases) in their interpretation of nutrient availability. Interpretive criteria differ for different crops; there is no single critical nutrient level or soil pH value that applies to all crops. Interpretation may be based on years of experience in working with farmers in a given region. If such experience is lacking, it may have to be developed. In the United States, for example, different state laboratories have different interpretative criteria for the same crop, based on experience within their state. In South Africa, several blenders often compete for the business of commercial farmers, and their comparative advantage relies in part on how well they interpret analytical results to generate recommendations. In the smallholder farmer context, it should be borne in mind that one does not need to generate “perfect” interpretation; one only needs to generate data using recognized methods from which interpretations can be derived, and best-bet formulae can be developed and tested. Best-bet formulations should provide a nutrient balance for long-term sustainability, addressing the predominant nutrient constraints and, most importantly when field-tested, show superior yields and returns on investment compared to currently used fertilizers.

Fertilizer providers and blenders should contribute their expertise in initial formulation of best-bet treatments, based on the ingredients and processes they use, as they will provide products to the market. Inexperienced blenders often have no experience with formulation and may simply rely on the customer (or project) to come up with new products. In many instances, ingredients for balanced blends may not exist within the country, particularly micronutrients, and blenders may not be willing to invest in volume purchases of new ingredients until response has been established.

Technology transfer involves getting improved fertilizers to the market. The actions required are country-specific and depend upon a host of factors, including the subsidy environment, fertilizer regulations which may not address new ingredients, the presence of qualified blenders, and the volumes of product required. If very large volumes are required (>5,000 mt of a specific formula), fertilizers may be more economically produced as compounds rather than blends. A compound is a fertilizer in which all the ingredients are included in each fertilizer granule, whereas blends are mixtures of granular fertilizers, sometimes coated with micronutrient powders. By contrast, blends may be economically produced at much smaller volumes (as low as 5 mt) and thus provide greater flexibility to meet local requirements.

Fertilizer Policies and Regulations

From the beginning, it is important to understand the fertilizer regulations and the fertilizer policy of the country in which one is working, including the fertilizer subsidy environment. Some countries have regulations that only allow registered ingredients. Others impose taxes on nutrient sources not explicitly included. Many fertilizer regulations are crafted only for commodity fertilizers, which may make introduction of new fertilizers time-consuming. Other countries have imposed long evaluation periods for new fertilizers, which is prohibitive for fertilizer blenders that may produce many custom formulations annually. Some have overly restrictive limits on fertilizer attributes such as contaminants or moisture contents that are outside of international industry norms.

Regulations in many African countries were designed primarily for commodity fertilizers and are understandably not intended to accommodate innovative or new fertilizer products or blends. While some countries have reasonable requirements, such as ensuring that products meet the stated nutrient concentrations, others have very prohibitive regulations that require several years of trials to prove efficacy. Some of the existing fertilizer policies seem to be a copy of the pesticide registration policy, which is understandably more stringent.

In developing a facilitative regulatory and policy framework, regulatory bodies may require guidance in understanding the issues around new fertilizer products, including international norms and best practices, and their relevance to facilitating market entry of new products. Regional harmonization of national policies is ongoing through the Common Market for Eastern and Southern Africa (COMESA) and the Economic Community of West African States (ECOWAS), but it is not yet clear if this will result in a facilitative environment or when new regulations may come into effect. Harmonization of accredited labs that can be used across the region for fertilizer testing would also be beneficial.

Fertilizer Subsidies

When implemented, fertilizer subsidies can work to support or to discourage the use of better fertilizers, so it is important to understand the subsidy environment and work with those in charge of their implementation. In most countries, only commodity fertilizers are subsidized. Thus, balanced fertilizers must compete against lower cost subsidized fertilizers. Since cost is a major consideration for most smallholder farmers, they will often choose the least expensive fertilizer and forgo purchases of higher cost fertilizers, even though higher yields usually more than compensate for the subsidy cost.

A more open policy that would allow farmers to purchase any fertilizer on subsidy could potentially be implemented using a well-regulated fertilizer voucher program. However, there are often political impediments to this process. Lack of transparency in fertilizer procurement is common, with procurements going to companies in return for “facilitation fees.” Overcoming entrenched interests in subsidy programs will be a major challenge in some countries.

On the other hand, if the superiority of balanced fertilizers vs. traditionally subsidized commodity fertilizers is established, governments may encourage the use of better fertilizers by changing the fertilizers they subsidize. This requires communication with those in charge of subsidy programs, as well as independent evaluation, usually in collaboration with national agricultural research systems.

Farmer Awareness and Marketing

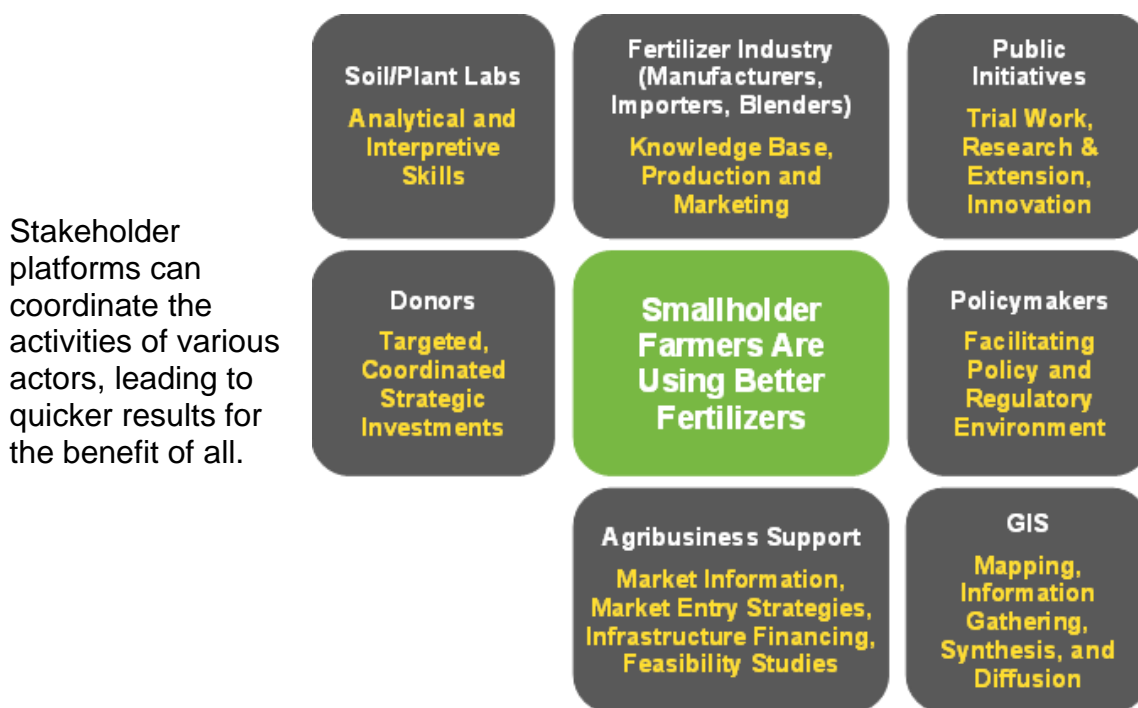
In a liberalized fertilizer environment, companies are free to market fertilizers that meet regulatory standards. Different companies have different approaches, which may involve farmer demonstrations, distribution of fertilizer small packs to agro-dealers, extension personnel, lead farmers, advertising through various media, promotional materials with agro-dealers, and liaising with key agricultural personnel at district and country levels. A company may also wish to engage national and farmer organization extension services in field demonstrations. Non-governmental organizations involved in projects that incorporate fertilizer use may also be engaged. In other countries, permissible fertilizers, as well as fertilizer distribution channels, are tightly controlled. In such cases, one must engage with governments at an early stage and work through government entities to get new fertilizers into the market.

Navigating the SMaRT Pathway Together

The SMaRT approach involves the coordination of multiple stakeholders, including smallholder farmers and their associations, analytical service providers, national and international research and extension organizations, fertilizer manufacturers and blenders, those involved in fertilizer distribution, sales and infrastructure, donors, market information service providers, fertilizer policymakers, national regulatory bodies, financiers, and mapping and GIS experts.

All actors possess unique experience and knowledge that relate to their primary functions. Yet, many stakeholders are siloed, sometimes not appreciating skills outside of their organization or expertise, and occasionally are in competition with one another for business opportunities or funding. Increased interaction between the multiple stakeholders will accelerate implementation of the SMaRT pathway and is ultimately to the benefit of all. Mechanisms of collaboration need to be established in the form of stakeholder platforms at various levels.

The figure below gives a generalized overview of national agricultural and fertilizer sectors applicable to sub-Saharan African countries, the multiple opportunities in these sectors, the concept of the fertilizer sector roadmaps and its goals, the intervention areas and the outcomes.



Dr. John WENDT
Senior Soil Fertility Expert
International Fertilizer Development Center (IFDC)
c/o IFDC/ICIPE, PO Box 30772-00100, Nairobi, Kenya
Email: jwendt@ifdc.org

Lilian Wanjiru MBUTHIA
Regional Coordinator
International Potash Institute (IPI)
P.O. Box 29183-00100 GPO, Nairobi, Kenya
Email: lilianwanjiru.mbuthia@icl-group.com



Developing Agriculture from the Ground Up