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

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Abstract

Most smallholder African farmers have access to only NP and NPK fertilizers. A host of secondary and micronutrient deficiencies have been identified throughout the continent, which when addressed, results in marked yield improvement. A challenge is to get balanced fertilizers (those that supplement available fertilizers with secondary and micronutrients) to these smallholders, who often can neither afford nor access quality soil analyses. We lay out a conceptual framework, which is being implemented to varying degrees in various African countries, to deliver improved fertilizers to smallholders. The SMaRT framework stands for Soil testing, Mapping, Recommendations development, and Technology transfer. Soil testing is done on a broad scale to identify major likely deficiencies, using complete analyses by a qualified laboratory. The major deficiencies are mapped, and crop-specific recommendations are developed through on-farm "best bet" and omission trials, considering predominant deficiencies and crop-specific nutrient demands. Once superior fertilizers have been validated, these recommendations are transferred to farmers by commercial fertilizer interests. Fertilizer regulations in many African countries need to be adjusted to accommodate new fertilizers, as regulations were often designed primarily for commodity NPK fertilizers.

Status of Fertilizer Use in Sub-Saharan Africa

Fertilizer use in sub-Saharan Africa is low, averaging 16 kg fertilizer per ha of arable land. This should 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 farmer use, a major problem facing smallholders is the lack of diversity of fertilizer products to address soil- and crop-specific demands.

The main fertilizers available to smallholder farmers are what are referred to as "commodity fertilizers," such as 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 generally not available. In many 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 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 usually improving yields, do not result in optimal nutrient response. Vast tracts of secondary and micronutrient deficiencies (primarily S, Zn, and B) and soil acidity constraints have been identified through various mapping initiatives, and superior response 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, often 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 are generally not targeted to soils and 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/ha) 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. Once getting a crop-specific recommendation for a desired yield target, they purchase in volumes that can reasonably be produced by a commercial blender – often more than 5 tons. They also have equipment that can efficiently apply fertilizers at variable rates that match recommendations.

Most smallholders' 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 to adjust NPK ratios to fit the soil analysis and crops. Even if 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 boron) and can induce other deficiencies. While some have proposed inexpensive field soil test kits for soil analysis, based on wet chemistry and more recently infra-red spectrometry, these generally measure only 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, which number in the millions. While soil test kits are still in development conceptually, yield improvements based on some kit analyses have yet to be validated.

The SMART Concept

SMART stands for Soil analysis, MApping, Recommendations development, and Technology transfer. 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 recommendations may be part of a SMART recommendation when lime is available and required. Some aspects of the SMART concept 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 efforts.

The goal is not to make the perfect fertilizer for every smallholder farmer and crop, but to develop fertilizers that substantially improve yields and economic returns compared to fertilizers currently available. With this target in mind, fertilizers can be produced for major crops in defined geographical areas in sufficient quantities to be commercially viable. This may mean that the fertilizers will contain nutrients that are not required for some farms, but result in an economic yield increase for the majority.

The SMART concept begins with **soil sampling**. A minimum sampling density of 25 km^2 (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. A sampling depth of 0-20 cm is desirable, though deeper samples (20-50 cm) can provide additional information on constraints such as subsoil acidity, subsoil nutrients such as S or Cl, or soil texture impediments. Samples receive a full analysis for all essential nutrients, soil pH, organic C, total N, and soil texture from a pre-evaluated qualified laboratory, using recognized procedures. While many procedures are "recognized" (there are at least three procedures commonly employed for most nutrients), some harmonization would be desirable to facilitate interpretation of results, as interpretation is dependent on the procedure used. Some of these analyses may be performed spectrally if good spectral calibrations 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. Mapping may concentrate on specific zones of production; for example, a rice marshland, 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, for crop-specific needs. Maps are also very powerful in informing policy and agricultural research priorities. Many countries are unaware of the extent of the various nutrient and soil acidity constraints affecting yields. Maps can spark interest in the need to develop and support balanced fertilizers.

Quality of Soil Analyses Required for Mapping

While complete quality soil analyses are somewhat 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 analyses, 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 and 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 analyses including soil pH, total N, organic C, P fixation capacity, and others where calibrations are good, and is well-calibrated for most total nutrients in plant tissue.

The **recommendation** 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 + 0.5 Zn + 0.2 B) indicate the percentages of nutrients in a blend or compound. When multiplied by the rate of application of the fertilizer (in kg/ha), the amounts of nutrients applied per ha are calculated.

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 types, and weather, among other factors. Other good agricultural practices such as timely planting and weeding should 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.

In developing recommendations, a starting point is to understand 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 N and P to offset extraction, even though a soil may have moderate available N and P, so that the developed fertilizer will be able to sustain a yield target without annual adjustment. Therefore, N and P rates are generally fixed based on crop extraction, unless for exceptional areas where high N and/or P that can sustain production for several years are observed. We have occasionally found such soils in high organic matter volcanic soils. P application may also consider the P-fixing potential of soils. For K, while extraction rates are high for many crops, return 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 sufficient. Most soils can provide some K, and for many crops including maize, tables have been constructed on K application 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 (B) or fixation (common with Zn and Cu). 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 run 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 on which nutrients belong in a formula and can be used to evaluate the economic impact of each nutrient and lime on yields.

For trials to have broad applicability, these trials 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 historically better management and thus not reflect on-farm realities. On-farm response data provide the economic justification for a fertilizer formulation, which informs fertilizer providers if they truly have a superior product. These trials can also provide the economic justification for changing fertilizers offered under subsidy programs. A minimum of 30 sites in a region with soil and climatic similarities usually provide sufficient statistical resolution to validate response.

Some may wish to forego 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 promotions and trial data, 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, and are therefore a public good. Any trial work, when run in collaboration with national governments, produces data that form the economic basis for changes in national recommendations and can be a valuable contribution to subsidy programs.

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 (which translates into a fertilizer rate), and a crop-specific interpretation of the 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 are added and are 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 reducing other nutrients, such that their addition need not affect fertilizer application rates.

The interpretation of the analytical results is not a straightforward process, and 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, 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. 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 lies in part in 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 the "perfect" interpretation; one only needs to generate data using recognized methods on which interpretations can be derived, and best-bet formulas 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 for 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. Actions required are country-specific, and depend on 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 t 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 every fertilizer granule, whereas blends are mixtures of granular fertilizers, sometimes coated with micronutrient powders.

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 for certain ingredients. Others impose taxes on fertilizer sources not explicitly included. Many fertilizer regulations are crafted only for commodity fertilizers, which may make introduction of new fertilizers time-consuming. Still others have required 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 industry norms.

Regulations in many African countries were designed primarily for commodity fertilizers, and are understandably not designed 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 seasons/years of trials to prove efficacy. Some of the existing fertilizer policies seem to be a copy/paste 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 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 product testing would also be beneficial.

Where implemented, fertilizer subsidies often work to discourage use of superior blends. In most countries, only commodity fertilizers are subsidized. Thus, superior balanced fertilizers must compete against these lower cost fertilizers. Since cost is a major consideration for most African smallholder farmers, they will often choose the least expensive fertilizer and forego purchase of higher cost fertilizers, even though the yield advantage of these fertilizers more than justifies cost. Lack of transparency in fertilizer procurement is common, with procurements going to companies in return for "facilitation fees" or procurements given to favored interests in spite of higher costs. Overcoming entrenched interests in subsidy programs is a major challenge in many African countries.

Farmer Awareness and Marketing

In a liberalized fertilizer environment where no fertilizer subsidies exist, 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, or lead farmers, advertising through various media, including 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. NGOs involved in projects that involve fertilizer use may also be engaged. In other countries, permissible fertilizers are tightly controlled, as well as fertilizer distribution channels. In such cases, one must engage with governments at an early stage, and work through government entities, to get new fertilizers into the market.