Analysis of Crop Nutrient Response Patterns to Guide Site-Specific Fertilizer Recommendations

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Large field-to-field variability in maize response to fertilizer additions indicates considerable differences in sub-Saharan African soil conditions.

Cluster analysis categorized results from on-farm trials to determine the variability in soils and crop productivity.

The technique effectively separated responsive from non-responsive fields, and further helps to identify the limiting factors to productivity.

Mr. Otieno (pictured) is part of a research team that is working to develop and disseminate site-specific nutrient management recommendations in sub-Saharan Africa.

Poor productivity of food crops due to low soil nutrient levels is a major contributor to food insecurity in sub-Saharan Africa (SSA) (Shapouri et al., 2010). Current investments to help farmers increase fertilizer use are not often supported by appropriate fertilizer recommendations (Giller et al., 2011), resulting in poor fertilizer use efficiency and low economic returns to investment in fertilizer (Nziguheba et al., 2009). Information that can help to target the right fertilizer source and application rates for specific crops and locations, is crucial for sustainable crop production intensification in smallholder farming systems.

Although crop fertilizer response categories based on the response, or lack of response, to nutrient application are generally recognized, there is currently no large-scale information on their occurrence, extent, distribution, or identifying soil property characteristics. This study was conducted across a range of sites in four countries in SSA to assess the prevalence and distribution of soil nutrients and soil constraints that limit crop productivity in major cereal-based cropping systems. It also had the objective of developing a simple system for classifying patterns of crop yield response to fertilizer. The study also determined the soil properties that characterize the classes of crop nutrient responses.

Nutrient omission trials for identifying soil fertility constraints were implemented in Kenya, Malawi, Nigeria, and Tanzania. In each country, between 23 and 49 on-farm locations were strategically selected to cover a wide range of soil conditions that are representative of high potential maize growing areas in East and West Africa. Field trials were conducted between 2009 and 2012. The field trials were implemented using a modified nutrient omission trial design (**Table 1**), with maize as the test crop (plant spacing was 0.75m x 0.25m). All field trials were designed and managed by researchers follow-

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; B = boron; Cu = copper; Fe = iron; Mn = manganese; Na = sodium; Zn = zinc; C = carbon; Al = aluminum; SOC = soil organic carbon; ppm = parts per million.

Table 1. Treatments implemented in Africa Soil Information Service (AfSIS) diagnostic trials.

Treatment	Description
Co	Control (no nutrient added)
NPK	Macronutrients added
-N	P and K applied (N omission)
-K	N and P applied (K omission)
-P	N and K applied (P omission)
+MN	NPK+Secondary and Micro-nutrients (Ca, Mg, S, Zn, B)
+MA	NPK+manure
+L	NPK+lime

Nutrients were applied at rates of 100 kg N/ha, 30 kg P/ha, 60 kg K/ha, 10 kg Ca/ha, 5 kg Mg/ha, 5 kg S/ha, 3 kg Zn/ha, and 3 kg B/ha. Manure was applied at 10 t/ha on a dry matter basis and lime at 500 kg/ha.

ing standard best agronomic management practices.

Soil sampling began at the start of the trials, before application of fertilizers and amendments. Soil samples were analyzed for major soil characteristics including organic C, total N, available P, S, B, Mn, Cu, Zn, K, Ca, Mg, Na, Fe, exchangeable Al, and pH. Crops were harvested at maturity in a net plot of 6.75 m^2 and grain yield was expressed on dry weight basis (12.5% moisture content).

Cluster analysis was conducted using K-Means clustering on the differences between the grain yield from a given treatment and the control treatment, to identify various classes of nutrient response patterns. A multinomial logit regression model was developed and used to identify the possible soil factors influencing the identified response clusters.

Four main clusters were identified as appropriate for categorizing observed nutrient responses. These clusters explained 60% of the variation in the yield data. Yields from the various treatments in each cluster were plotted (**Figure 1**), and the clusters were interpreted as followed:

Cluster 1: Fields where maize was not responsive to any nutrient application or soil amendments. The cluster was further disaggregated according to fertile soils (Cluster 1b in **Figure 1** referred to as fertile non-responsive fields) with high yields (attainable yield level between 4 to 5 t/ha) and infertile fields with low yields (Cluster 1a referred to poor non-responsive fields, attainable yield level remains below 2 t/ha) and have major limitations that need to be addressed before any nutrients or amendments can have any significant effect. 25% of the fields considered in this study were in this cluster.

Cluster 2: Fields with major N and P limitations and occasionally K limitations. Addressing N, P and/or K limitations results in yields up to 4 t/ha. The addition of manure further improved the yield substantially (by 40% over NPK), as well as adding multi-nutrients to the NPK (i.e., the +MN treatment) improved the yields significantly (by 23% over NPK). Average yields achieved with the appropriate inputs was about 5.5 t/ha. 36% of the fields fell into this cluster.

Cluster 3: Fields where maize had limited response to both nutrient application and further addition of amendments. While nutrient application increased yields, attainable yields were about 3 t/ha due to other constraints that limit yield response. 28% of the fields fell into this cluster.

Cluster 4: Fields with N as the major limiting factor. Maize was strongly responsive to N application but showed limited response to P and K. Addition of lime, multi-nutrients or manure further improve the yield. Attainable yield level with the appropriate macronutrient inputs is 5 t/ha, but can be increased to 6.5 t/ha with the required soil amendments. Fields in this cluster constitute 11% of the cases.

The majority of fields (36%) were located in Cluster 2, which showed a high response to N and P. This was in line with the general consensus in the region that N and P are the key limiting nutrients to crop production in SSA (**Table 2**). However, the high prevalence of poor non-responsive and low responsive soils in all countries indicate major challenges to increase crop productivity at large scale. The attainable yields in more than 50% of the fields were less than the first-step yield target of 3 t/ha. This target was set for the African Green Revolution in SSA (Sanchez, 2010) and is considered a realistic target when nutrient and other agronomic inputs are applied in adequate quantities.

Although only a small fraction of the fields were classified as non-responsive due to high fertility, such non-responsiveness is mainly expected in areas newly converted to cultivation or in fields close to homesteads that receive large applications of fertilizer and manure (Giller et al. 2011). The presence of these fields adds to the discourse on the need for site-specific

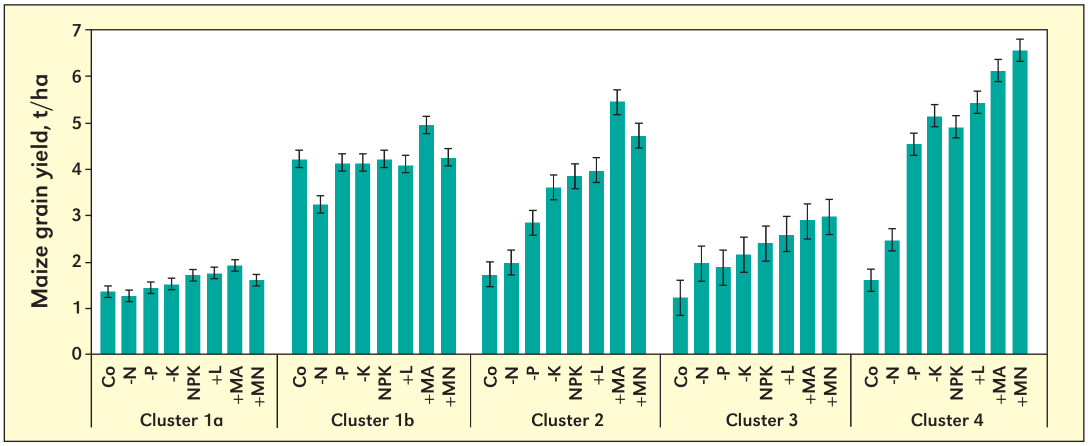

Figure 1. Maize grain yield observed from sub-Saharan Africa fields classified under different clusters following K-Means clustering. Error bars are standard errors of the estimates. Co = Control; -N, -P, -K = omission plots; NPK = macronutrients; +L = NPK+lime; +Ma = NPK+manure; +Mn = NPK+Ca, Mg, S, Zn, B.

Table 2. Occurence and soil properties of the main nutrient response clusters.

Variable	Cluster 1a (poor, non-responsive fields)	Cluster 1b (fertile, non-responsive fields)	Cluster 2 (fields responsive to N, P and manure)	Cluster 3 (low response fields)	Cluster 4 (fields highly responsive to N)
Fields per cluster, %	21	4	36	28	11
Soil properties					
pH	5.6	6.1	5.5	5.7	6.3
C, %	1.2	2.1	1.0	1.5	1.0
Ca:Mg	2.56	2.6	2.8	2.96	4.5
Na, ppm	24	26	30	31	37
P, ppm	17	11	11	18	46
Al, ppm	1,040	816	1,248	890	841
Mn, ppm	94	100	210	130	159
S, ppm	9.3	7.9	9.4	8.5	9.3
B, ppm	0.07	0.34	0.12	0.1	0.16
Zn, ppm	1.81	2.23	2.14	2.31	2.57

Soil property values represent the median. Critical lower limits (ppm) for micronutrients (DTPA extractable) are: Mn = 2; Fe = 4.5 (Sillanpaa, 1982); Cu = 1 (Lopes, 1980).

nutrient application based on individual field characteristics such as location, previous management, and farmer resource endowment. For example, fields in Cluster 2 may only require the application of fertilizer quantities geared at maintaining fertility in the short-term.

Soil data from the specific experimental fields within a site showed wide variability in major properties with median soil pH ranging from 5.2 to 6.4, and the available P from 3.6 to 52.8 mg/kg (**Table 2**). Cluster 4 was characterized by high responses to N and had very high levels of available P. The fields in the poor non-responsive category had the lowest Zn, B, Cu, Mn, and Na (**Table 2**). Using the poor non-responsive fields in Cluster 1 as the base category in the multinomial logit shows that increasing the soil Ca:Mg ratio is highly significant. As well, increasing soil contents of Zn, S, B, and Na, while simultaneously decreasing Al concentrations, was also significant. This required the poor non-responsive fields to move to the highly responsive category of Cluster 2, which is responsive to most of the nutrients and amendments. The poor non-responsive fields clearly had less C than the fertile non-responsive fields (1.4% vs. 2.0% C, respectively), in addition to the limitations due to low B and exchangeable bases.

The results from this study highlight the need for fertilizer recommendations that address the requirement of balanced fertilizer application, including micronutrients, under highly variable soil fertility conditions. Further, management of soils in SSA requires a clear distinction between those intermediate to highly responsive soils on the one hand, and the low to non-responsive soils on the other hand. For the responsive soils, the focus should be on optimizing management of inorganic nutrient inputs, including micronutrients, while maintaining soil organic matter management. For the low to non-responsive soils, attention should be placed on restoring the productivity through balanced nutrient management, improved soil water management, and application of organic resources to increase SOC and micronutrients in the medium term. It is important to highlight that significant crop productivity improvement in the short-term should not to be expected on these low and non-responsive soils (Zingore et al. 2008). Changes in land use, or selection of crops that are better adapted to degraded soils, could also be considered as options for rehabilitating degraded soils.

Summary

Current initiatives to intensify crop productivity in SSA are currently limited by the large variations in crop yield responses to applied nutrients observed between fields and regions. Analysis of data from multi-location nutrient omission on-farm trials indicates that maize crops in 11% of fields were highly responsive to N application, while 28% showed a low response and 36% showed an intermediate response to macro and micronutrients. A total of 21% of the fields were categorized as degraded and 'non-responsive' to any nutrient or soil amendment. Efforts to achieve sustainable crop production intensification in smallholder farming systems in SSA requires the development of management strategies which improve the efficient use of fertilizer and other cropping inputs. This work highlights the need for research to recognize the distinctive nutrient response patterns found on-farm in SSA, and to carefully consider their underlying soil properties.

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