Maize Productivity and Response to Fertilizer Use as Affected by Soil Fertility Variability, Manure Application, and Cropping System

By Shamie Zingore

Studies in sub-Saharan Africa (SSA) show that fertilizer use is consistently more profitable and efficient on fertile fields. When soils are degraded, restoration of soil fertility through balanced fertilization and organic matter additions is necessary to achieve high crop productivity. Other options for managing soil fertility, such as manure, crop rotations, and improved fallows are most effective when strategically combined with fertilizer.

Problems of declining soil fertility are widespread in SSA, largely as a consequence of continued cultivation of crops with low levels of nutrient inputs. To counter growing food insecurity, there are renewed efforts to support the predominantly subsistence farmers to intensify crop production mainly by increasing the use of fertilizers and improved crop varieties. Soil fertility varies considerably at the farm and landscape levels in many smallholder farming systems in Africa, leading to variable crop productivity and crop response to additions of fertilizer and organic nutrient resources (Zingore et al., 2007).

Consequently, large yield gaps arise from soil fertility differences between fields due to a combination of inherent and management factors. Therefore, a major focus should be placed on properly addressing the fundamental issues of providing the crops with adequate nutrients under highly variable soil fertility conditions. Despite a generalized trend of decreasing soil fertility in SSA (Stoorvogel et al., 1993), rates of change in soil nutrient stocks differ between farms and fields within farms. Smallholder farmers typically have limited amounts of nutrient resources that are preferentially used on fields closest to homesteads, leading to steep gradients of decreasing soil fertility with increasing distance from homesteads (Prudencio, 1993). This, combined with inherent variation in soils, results in complex variability in soil fertility between fields on the same farm or between farms differing in access to resources for crop production. Challenges exist to restore agricultural productivity for degraded soils that respond poorly to commonly used NP fertilizers. This article reviews the extent to which variability in soil fertility affects crop productivity, and crop response to fertilizer and various complementary organic resource-based technologies in the sub-humid zone of southern Africa.

The sub-humid zone constitutes 38% of the total land area in SSA and has good prospects for agricultural growth due to favorable rainfall (700 to 1,200 mm/yr) and high potential for maize production. Maize is the staple food crop for the region (FAO, 2002). The soils in SSA are inherently infertile and have been used for agricultural production for many decades with little or no addition of nutrient resources, leading to declining soil fertility (Bationo et al., 1998; Bekunda et al., 1997). Nutrient depletion rates for NPK range between 22 and 72 kg/ha/yr...a reflection on the low yields over the past 5 decades...with cereal productivity in SSA stagnant at about 1 t/ha. Long-term experiments show that with no fertilizer use, yields decline rapidly from an initial level of 5 t/ha when native woodlands are cleared for cultivation, to about 1 t/ha after 3 years **(Figure 1)**.

Abbreviations: N = nitrogen; P = phosphorus; K = potassium; B = boron; Ca = calcium; Zn = zinc.

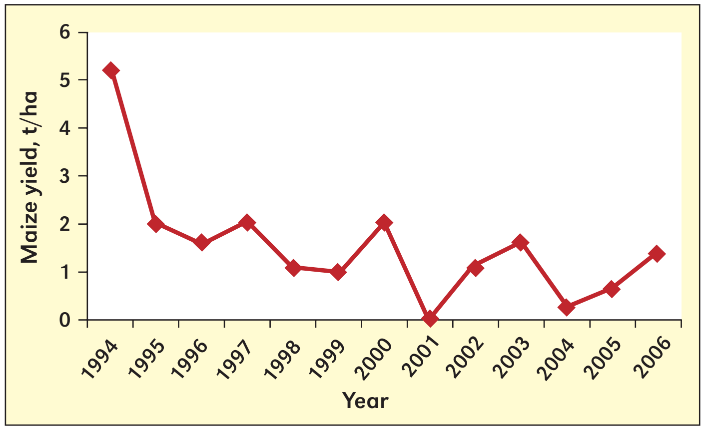

Figure 1. Average maize yields with no fertilizer application from long-term experiments in southern Africa (Waddington et al., 2007).

The use of mineral fertilizers in SSA has been promoted through blanket recommendations that are based on agro-ecological zones. Improving the blanket recommendations to account for variability in soil fertility between land units is necessary to maximize the benefits of projected increases in fertilizer use. Multi-location trials conducted across SSA revealed that baseline yields and yields for different fertilizer treatments increased with increasing soil fertility status (Tittonell et al., 2005; Zingore et al., 2007). Application of N alone gave the largest yield increase for all treatments and for all categories of soil fertility.

Addition of P also led to a significant increase in yields on the high fertility fields, but in medium fertility fields, addition of base cations (K and Ca) and micronutrients (Zn and B) was required to significantly increase crop yields above the N treatment **(Figure 2)**. On the depleted soils, baseline yields were very low, and were increased to less than 1 t/ha by applying N and to less than 2 t/ha by applying N and P. Under such conditions, an increase in soil organic matter can increase the retention of nutrients and water, better synchronize soil nutrient supply with crop demand, and improve soil health through greater soil biodiversity (Vanlauwe et al., 2010). In nutrient depleted soils, strategic fertilizer application with incorporation of crop residues over several seasons would be

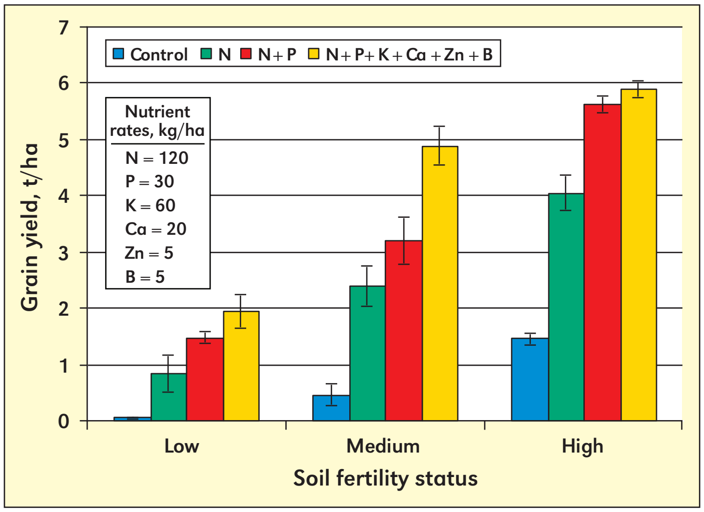

Figure 2. Maize yield response to various nutrient combinations as influenced by soil fertility status.

necessary to increase attainable yields over time. Alternative organic nutrient resources, such as compost and animal manures, may also play an important role in replenishing soil fertility, but available quantities are limited and the quality is often very poor.

Table 1. Maize productivity (t/ha) as affected by N fertilizer and manure application under low and medium soil fertility conditions.

	Control	Manure	N fertilizer	Manure + N fertilizer
Low soil fertility	0.3	0.8	1.2	2.8
Medium soil fertility	0.8	1.7	3.8	4.3
Standard error of difference (SED)	0.12	0.23	0.19	0.24

On low and medium soil fertility conditions, combined application of N fertilizers and manure led to increased productivity above fertilizer treatments alone, and this is most pronounced on degraded soils **(Table 1)**. Many studies in SSA have reported on the positive interaction between fertilizer and manure, with the benefits of manure increasing with decreasing soil fertility (Zingore et al., 2008; Mtambanengwe and Mapfumo, 2005).

Various legume-based technologies, such as rotations of cereal crops with grain legumes, improved fallows, alley-cropping, and green manures have been advocated as viable options for providing supplementary N to cereal crops through biological N fixation (Giller et al., 1997). Within rotations, applying P to grain legumes has variable effects on the subsequent maize crop. The yield of maize following groundnut was greater than continuously fertilized maize, but soybean had no effect on maize productivity **(Table 2)**. Groundnuts can double the yields of the subsequent season maize crop without fertilizer, but gave more additional grain yield when fertilizer was used on the maize.

Intercropping maize with grain legumes offers opportunities to improve overall productivity of both crops, and

Differences in response to fertilizers under low (top photo), medium (middle), and high soil fertility conditions.

Table 2. Rotational effects of grain legumes on productivity of maize in fertilized and unfertilized crop rotations.

	--------- Without fertilizer ---------			--------- With fertilizer ---------		
Legume crop	Continuous maize, t/ha	Maize after legume, t/ha	Rotation yield gain, %	Continuous maize, t/ha	Maize after legume, t/ha	Rotation yield gain, %
Groundnut	1.7	3.0	44	4.4	5.9	25
Soybean	1.1	1.5	24	2.0	2.0	0
SED	0.22	0.26		0.33	0.25	

Table 3. Cost and benefits (USD/ha) of fertilizer use by sole maize and maize-bean intercrop.

Crop system	Maize benefit	Bean benefit	Costs that vary	Net benefit
Sole maize	55	0	31	24
Maize + bean	48	45	42	51

ensure the legumes benefit from fertilizer targeted to maize. Intercrops can result in increased grain output over maize alone, both with and without fertilizers (Snapp and Silim, 2002). Although maize yields when intercropped with beans were lower than for sole maize, the overall economic benefits of fertilizer use were greater for the intercrop than a maize monocrop due to the added benefits of the bean yield. An economic analysis of a maize-bean intercropping system showed that both fertilized and unfertilized intercrops had greater economic returns than corresponding sole maize crops, and that the economic viability of intercrops was substantially increased by fertilizer application **(Table 3)**.

A meta-analysis of fertilizer response under agroforestry in smallholder farming systems showed that fertilizers give the better maize yield response than legume trees and green manures (Sileshi et al., 2008). However, maize yield response to fertilizer application in the tree legumes systems was significantly higher than in green manures, natural fallows, and unfertilized maize. Based on the analysis, amending the post-fallow plots with 50% of the recommended fertilizer rate increased yields by more than 25% over similar plots that were not fallowed. Adding 100% of the recommended fertilizer to the post-fallow plots did not significantly increase yields over the yield obtained with 50% of the fertilizer treatments, as this resulted in oversupply of N. Tree legumes can play an important role in increasing fertilizer use efficiency, especially when fertilizer availability or amounts are limited.

Strategically targeting fertilizer use to variable soil fertility conditions, combined with recycling crop residues, manure application, and various legume-based technologies is necessary for viable fertilizer use in smallholder farming systems in SSA (Giller et al., 2006). Recognition of the spatial heterogeneity within smallholder farms will help to design more effective recommendations that target different soil fertility niches (i.e., poorly-responsive fertile fields, responsive fields, and poorly-responsive poor fields).

However, it is also necessary to develop communication/extension frameworks to build capacity among extension and industry field staff and smallholder farmers for the practical identification of such variability and its effect on fertilizer use and other management interventions. This will allow farmers to fine-tune their decision-making for the allocation of their scarce (labor, cash, and nutrient) resources. BC

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