Role of Soil Productivity in Nutrient and Water Use in Zimbabwe

By Natasha Kurwakumire, Regis Chikowo, Adrian Johnston, and Shamie Zingore

Addressing soil variability is a critical part of making site-specific fertilizer recommendations. Research in Zimbabwe evaluated crop yield responses on soils varying in organic carbon content. The research confirms balanced nutrient management had an overriding effect on maize grain yield and water productivity, but only when soil organic carbon (SOC) was >4 g/kg soil.

Dr. Regis Chikowo, University of Zimbabwe addresses local farmers at a field experiment site.

The challenges of inherently poor soil fertility, prohibitive costs and limited access to crop production inputs, and recurrent droughts have plagued smallholder farmers in Zimbabwe for generations. Rainfed agriculture is the most common practice, and as little as 20 to 40% of seasonal rainfall is used in crop production due to high runoff and evaporation. Poor nutrient and soil water availability has resulted in maize grain yields rarely exceeding 1.5 t/ha on these farms for the past 5 to 6 decades.

Historic management of farms, including fertilizer and manure management, straw return and erosion, have led to significant spatial variation between and within farms. While soil types impact some of this variation, resource endowment and preferential application of fertilizer and manure close to the homestead have accentuated these productivity gradients (Zingore et al., 2007). Given the impact of these gradients on nutrient use efficiency and yields across farms, targeting nutrient application tactfully becomes an important management practice for resource-constrained farmers (Vanlauwe et al., 2006, 2011).

It is important to point out that a number of soils in sub-Saharan Africa have been classified as "poorly or non-responsive" due to complex chemical imbalance and poor physical structure which inhibit crop response to fertilizers (Vanlauwe et al., 2002, 2011; Zingore et al., 2007). Unfortunately, fertilizer recommendations in Zimbabwe are based on the assumption of resource (soil and water) homogeneity and differentiated only by agro-ecological zone. This study was carried out to assess the response of maize to fertilizer inputs across a gradient of soil quality, and evaluate how nutrient management impacted both grain yield and water productivity.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; AN = ammonium nitrate; KCl = potassium chloride; SSP = single superphosphate.

The study was carried out in Dendenyore Ward, Wedza District of Eastern Zimbabwe. This region has annual precipitation of >800 mm and a mean temperature of 24°C during the November to April production season. The soils are sandy Lixisols with low SOC and poor nutrient supply potential. The trials were conducted on three farms, all within a 1 km radius, and varying in SOC. Type 1 soils had ≤4 g SOC/kg soil, Type 2 with >4 to 6 g SOC/kg soil, and Type 3 with >6 g SOC/kg soil. Productivity, historic input management, and clay content increased from Type 1 to Type 3 soils.

Fertilizers were applied using five treatments, including: 1) control; 2) N and K (AN + KCl); 3) NPS (SSP + AN); 4) PKS (SSP + KCl) and 5) NPKS (compound fertilizer 7-14-7-8 + AN + KCl). Target nutrient rates were 120-40-60-22 kg N-P_2O_5-K_2O-S/ha, with 20 N and all P, K and S applied at planting and 50 N at two advanced growth stages. In year 2 of the study, the target rate was changed to 120-20-30-11 kg/ha. However, in both years of this project, drought conditions prevented the second N split, so only 70N was applied.

Maize grain yields were significantly increased by the addition of fertilizers on all soils of the study area in both years

Dr. Chikowo demonstrates the yield gap using plots that received NPKS fertilizer versus the zero fertilizer check.

Table 1. Maize grain yields response to fertilizer additions on three soils differing in soil organic carbon (SOC), 2011/12 and 2012/13.

Soil Type		Check	NK	NPS	PKS	NPKS	$LSD_{0.05}$
		Grain yield, kg/ha					
Type 1	Year 1	280	400	1,400	310	1,465	198
≤4 g SOC	Year 2	200	730	1,360	240	1,440	210
Type 2	Year 1	1,000	1,720	2,900	1,300	3,190	200
>4 to 6 g SOC	Year 2	810	2,373	3,653	1,200	3,400	200
Type 3	Year 1	1,100	2,400	3,700	1,690	3,750	250
>6 g SOC	Year 2	1,200	1,378	3,200	1,100	3,560	190

(**Table 1**). The low SOC Type 1 field did not show a grain yield response to NK or PKS in year 1; however, the site did respond to the NPS and NPKS treatments. This indicates that these Type 1 soils are nutrient responsive and would not be categorized as non-responsive soils. In almost all cases, no difference was observed between the NPS and NPKS treatments, suggesting that indigenous soil K supply was sufficient to meet yields approaching 5 t/ha. The abundance of feldspar minerals in these granite-derived sandy soils in Zimbabwe provided an adequate K reserve at these yield levels (Nyamapfene, 1991).

The check yield for Type 1 soils was only one-quarter to one-sixth the yield of the check for Type 2 and 3 soils, indicating the significant impact of higher SOC on crop productivity. Similarly, compared to the check, the grain yield response for the NPKS treatments was 5 to 7 times for Type 1 soils, and 3 to 4 times for Type 2 and 3 soils. The NPKS yield for Type 1 soils was only marginally greater than the check yields of Type 3 soils, indicating a large yield gap that is associated with low soil organic matter, soil acidity, and possible deficiency of secondary and micronutrients. These maize yield responses clearly illustrate that fertilizer recommendations must be made on a site and soil specific basis in order to take into account these vast differences in production potential.

In this study, field Types 2 and 3 had comparable yields, supporting the existence of a critical SOC threshold of about 4.6 g/kg soil (Mtambanengwe and Mapfumo, 2005). Confirmation of this helps farmers in the allocation of scarce organic resources to those low SOC fields where the greatest improvement in productivity can be achieved. The responses from this range of soils also illustrate that for a modest application of fertilizer nutrients, very large yield increases can be captured, illustrating the productive potential of these soils in meeting future food security needs in Zimbabwe.

Similar to the grain yield responses, water productivity showed a significant positive increase with fertilizer additions on all soil types (**Table 2**). The positive role that balanced

Table 2. Water productivity as influenced by nutrient management across three experimental sites, 2011/12 and 2012/13.

Soil Type		Check	NK	NPS	PKS	NPKS	$LSD_{0.05}$
		kg grain/mm rain					
Type 1	Year 1	0.33	0.37	1.68	0.48	1.76	0.16
≤4 g SOC*	Year 2	0.22	0.82	1.53	0.27	1.62	0.20
Type 2	Year 1	1.20	1.83	3.49	1.82	3.84	0.18
>4 to 6 g SOC	Year 2	0.91	2.66	4.10	1.35	3.82	0.15
Type 3	Year 1	1.19	3.54	4.09	2.03	4.42	0.17
>6 g SOC	Year 2	1.35	1.55	3.59	1.23	4.00	0.23

*SOC = soil organic carbon.

nutrition plays in improving the grain production per unit of rainwater is clearly illustrated in this study. Having a flexible system of fertilizer N application, where the second top dress application could be applied only with sufficient soil moisture, provided the farmers with the opportunity to reduce losses from unnecessary input additions. This type of flexibility becomes critical as part of any crop productivity enhancement program in rainfed regions.

The results of this study clearly show that balanced nutrient management had an overriding impact on maize grain yields and water productivity, but this effect only occurred when SOC was greater than 4 g/kg soil. These results highlight the importance of management of limited organic resources in smallholder farming systems, and support the targeting of these resources on low SOC fields where the potential for greatest improvement in productivity can be achieved. BC

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Ms. Kurwakumire is an M.Phil. graduate and Dr. Chikowo is a Professor of Agronomy, University of Zimbabwe, Harare, Zimbabwe. Dr. Johnston is Vice President IPNI Asia, Africa & Middle East Group. Dr. Zingore is Director, IPNI sub-Saharan Africa Program.

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