Managing Degraded Soils with Balanced Fertilization in Zimbabwe

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Results from a long-term study showed that maize yields on depleted soils were marginally increased with multi-nutrient fertilizer application, while N fertilizer application alone resulted in lower yields on both sandy and clay soils. However, largest maize yields after nine seasons were achieved with cattle manure + fertilizer N application.

Low and declining soil fertility are recognized as major factors underlying low crop productivity in sub-Saharan Africa (Sanchez, 2002). Complex spatial and temporal variability in soil fertility associated with different soil types and contrasting management practices on different fields pose challenges for developing appropriate nutrient management recommendations.

On depleted soils, balanced nutrient management provides an opportunity to not only increase crop productivity, but also provides an option for rebuilding soil organic matter. This article outlines results from a long-term experiment conducted in northeast Zimbabwe. Its objective was to assess the long-term impact of various nutrient management practices on maize productivity within the contrasting soil types and regional management histories.

Two farms were selected for the study—one with a sandy soil (85% sand and 13% clay) and the other with a clay soil (42% sand and 44% clay). On each of these farms, two fields were selected with contrasting soil fertility conditions based on management history. One field had received annual additions of at least 5 t/ha manure and 50 kg/ha of N fertilizer, while the other field had been cultivated continuously with no manure and very little fertilizer (i.e., <10 kg N/ha). The four fields had variable soil properties and were classified as: standard sandy soil (SS); depleted sandy soil (DSS); standard clay soil (CS) and; depleted clay soil (DCS). Initial characterization showed that all soils were low in organic matter and available P, whereas K was deficient only in the sandy soils (**Table 1**). Experimental treatments were laid out in a randomized complete block design with three replications on 6 m × 4.5 m plots in each field. The experiment was run for nine consecutive seasons starting with the 2002-2003 season, with one crop of maize each year. Treatments included: (a) control (no fertilizer and/or manure added); (b) 100 kg N/ha; (c) 100 kg N/ha + 15 t manure/ha (i.e., fertilizer N + manure application, with manure adding about

Abbreviations and notes: N = nitrogen; AN = ammonium nitrate; SSP = single superphosphate; P = phosphorus; Ca = calcium; Mg = magnesium; Fe = iron; Cu = copper; Mn = manganese; Zn = zinc; CEC = cation exchange capacity.

Effects of manure + N on maize productivity on a depleted sandy soil.

Table 1. Initial and final soil chemical properties after nine seasons of manure and mineral fertilizer application on different soils and field types in Zimbabwe.

Soil	Field type	Treatments	C, %	N, %	pH	Available P, mg/kg	CEC, $cmol_c$/kg	Ca, $cmol_c$/kg	Mg, $cmol_c$/kg	K, $cmol_c$/kg	BS[1], %
Sandy	Standard	Initial	0.50	0.04	5.10	7.2	2.2	0.9	0.32	0.21	73.0
		Control	0.40	0.03	5.38	6.6	2.5	1.5	0.45	0.17	57.9
		100N	0.29	0.03	5.26	8.9	2.8	1.1	0.35	0.15	57.8
		100N + 15t manure	0.50	0.04	5.29	8.4	4.8	1.9	0.65	0.31	61.5
	Depleted	Initial	0.30	0.03	4.90	2.4	1.6	0.3	0.19	0.11	37.0
		Control	0.34	0.03	5.00	2.0	3.3	0.9	0.36	0.10	45.8
		100N	0.30	0.03	5.08	4.3	2.8	0.9	0.34	0.12	51.7
		100N + 15t manure	0.39	0.03	5.12	8.4	3.9	1.3	0.49	0.21	53.2
Clay	Standard	Initial	1.40	0.08	5.60	12.1	24.2	11.5	6.20	0.80	78.0
		Control	1.38	0.05	6.44	10.4	19.6	10.3	5.38	0.67	83.1
		100N	1.37	0.05	6.47	10.9	22.8	11.5	8.76	0.58	87.8
		100N + 15t manure	1.63	0.08	6.52	15.4	24.3	12.9	7.94	1.24	90.5
	Depleted	Initial	0.80	0.05	5.40	3.9	22.0	8.4	6.30	0.30	68.6
		Control	0.67	0.05	6.46	3.8	20.3	8.1	6.07	0.51	73.0
		100N	0.76	0.06	6.52	4.3	27.9	14.7	10.52	0.49	90.5
		100N + 15t manure	0.87	0.06	6.51	10.0	28.1	14.6	10.32	0.82	89.0
		SE[1]	0.11	0.00	0.14	0.84	2.51	1.28	0.92	0.09	3.82

[1]BS = Base Saturation; SE = Standard Error.

to 30 kg P/ha); and (d) 100 kg N/ha + 30 kg P/ha + 25 kg S/ha + 20 kg Ca/ha + 5 kg Mn/ha + 5 kg Zn/ha (i.e., multi-nutrient fertilizer application).

Mineral N fertilizer was applied using AN (34.5% N) and other fertilizer nutrients (P, Ca, Mn and Zn) were applied using a blend of SSP, and sulfates of Ca, Mn and Zn, which together with SSP supplied S. Aerobically composted cattle manure was applied annually on a dry-weight basis. To reduce variability, cattle manure was collected from the same farm every year and was generally of medium quality with a C:N ratio of 25 and contained macro- and micronutrients as follows: 1.1% N, 0.18% P, 0.20% Ca, 0.08% Mg, 0.64% K, 800 mg Fe/kg, 22 mg Cu/kg, 280 mg Mn/kg, and 112 mg Zn/kg. Manure was spread evenly on the surface covering the whole plot and incorporated into the soil (0 to 20 cm) using hand hoes before planting. Basal and top-dressing fertilizer was spot-applied

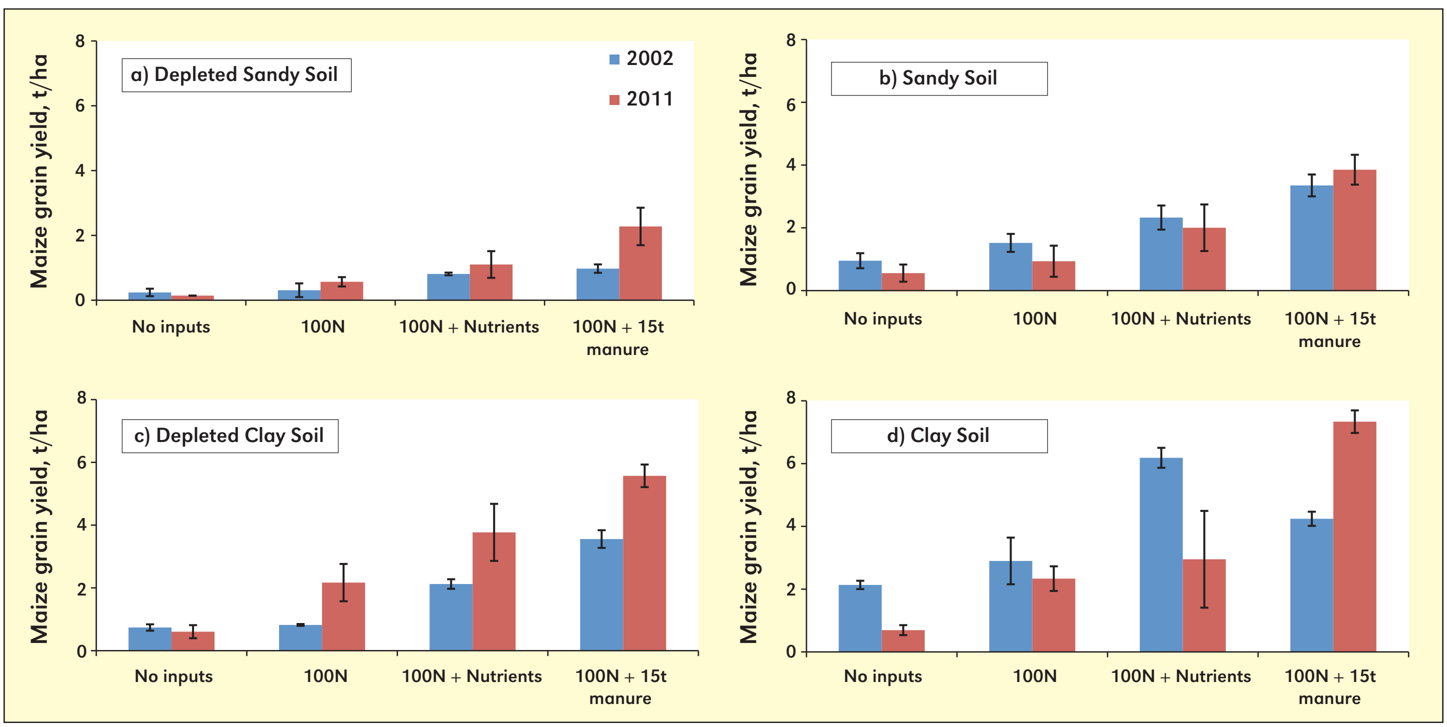

Figure 1. Initial and final maize yields and yield responses to long-term application of manure and mineral fertilizers under variable soil fertility conditions in Zimbabwe. Bars represent standard error of means.

Table 2. Gross margins with different fertilizer and manure application treatments under variable soil fertility conditions in Zimbabwe.

Soil type	Field type	Treatment	Yield, t/ha 2002/03	Yield, t/ha 2010/11	Cost of seed and fertilizer, US$/ha	Gross Margin*, US$/ha 2002/03	Gross Margin*, US$/ha 2010/11
Clay	Standard	Control	2.13	0.69	55	745	205
		100N	2.90	2.33	246	840	629
		100N + multi-nutrient fertilizer	6.18	2.95	376	1,943	730
		100N + 15t manure	4.24	7.34	741	849	2,009
	Depleted	Control	0.74	0.60	55	221	171
		100N	0.82	2.17	246	61	567
		100N + multi-nutrient fertilizer	2.12	3.77	376	420	1,037
		100N + 15t manure	3.56	5.57	741	592	1,347
Sandy	Standard	Control	0.95	0.56	55	302	153
		100N	1.52	0.94	246	323	104
		100N + multi-nutrient fertilizer	2.33	2.00	376	496	374
		100N + 15t manure	3.35	3.85	741	515	703
	Depleted	Control	0.24	0.14	55	34	-1
		100N	0.31	0.57	246	-130	-32
		100N + multi-nutrient fertilizer	0.81	1.10	376	-72	37
		100N + 15t manure	0.98	2.28	741	-375	112

*Gross margins were calculated using the farm gate price of maize grain of US$375/t and costs of 1 kg of N applied as ammonium nitrate = US$0.63; 1 kg of P supplied as multi-nutrient fertilizer blend = US$4.3; 1 t of manure = US$33; 1 kg of maize seed = US$2.2.

at each planting hill. Ammonium nitrate was applied as top-dressing in two 50 kg N/ha amounts at three and six weeks after crop emergence in all plots except the control. A medium maturity, drought tolerant hybrid maize cultivar (SC525) was planted at a spacing of 90 cm × 25 cm. All plots were weeded manually four times during each season. Gross margins for the different fertilizer treatments on each field were calculated by subtracting the cost of inputs (seed, manure and fertilizer) from the value of the maize produced.

Effects of Balanced Nutrient Management on Maize Productivity

Maize yields in control plots were lower in sandy soil than clay soil, and in the depleted fields (DSS and DCS) compared to un-depleted CS and SS, respectively (**Figure 1**). This was associated with lower indigenous nutrient supply capacity in the sandy versus clay-textured soils, and the depleted versus undepleted soil fertility.

Balanced fertilizer application increased yields in the long run in all soil types, except in sandy soils, where the increase was marginal. Fertilizer application alone, however, decreased maize yields in SS and CS over the nine cropping seasons. In the CS, larger maize yields were produced in the first year (2002) with mineral fertilizers alone than the fertilizer N + manure treatment, but this trend was reversed after nine seasons (**Figure 1d**). The lower yields with fertilizer after nine seasons were associated with lack of K application and removal of all crop residues after harvesting.

The results showed that the four field types we studied followed different pathways in rebuilding soil fertility as shown in maize grain yield trends. Although fertilizer is considered critical for sustainable crop production, the potential to restore soil fertility on the DSS through application of fertilizer alone was very poor. This is an example of the deviation between the pathways of soil fertility decline and restoration, which often act as a disincentive to smallholder farmers because building up soil fertility takes much more time than is required to deplete it (Tittonell et al., 2012). The small response in soil fertility build-up was more pronounced on the depleted sandy soils due to a combination of previous inadequate nutrient management and inherent infertility. In these soils, manure in combination with N fertilizer application was necessary to prevent long-term decline in yields as there was an increase over time in the yield difference between mineral fertilizer alone and fertilizer N + manure management strategies.

Crop yields with fertilizer N + manure were always larger than with mineral fertilizer alone at equivalent P application rate in sandy soils; this could have been due to K deficiencies. Potassium availability was especially poor in the sandy soils (**Table 1**), but was not included in the fertilizer alone treatments due to a general lack of K fertilizer in the region. Results suggested that manure + fertilizer N application proved better to mineral fertilizer application alone due to an increase in (a) the soil organic carbon and (b) the supply of K. A large portion of P and K in manure is often inorganic, thus manure is a good source for these nutrients (Eghball et al., 2002).

Effects of Balanced Nutrient Management on Soil Properties

Compared with the initial values, soil fertility generally declined with fertilizer application alone during the experimental period, except for a few elements like available P, Ca and Mg (**Table 1**). However, long-term application of manure versus N fertilizer alone increased or maintained the N concentration in all soil types, greatly increased available P, especially in depleted soils, and increased CEC and base cations, with more pronounced effects observed in sandy soils compared to the clay soils. Available P was kept near its initial level in

Variability in crop productivity within a smallholder farm in Zimbabwe.

non-depleted sandy soil, due to its history of receiving manure. This result contrasts with unmanured, depleted sandy soil that had very low initial P and therefore a net gain in P fertility. Soil organic carbon content greatly increased with fertilizer N + manure application treatment compared to the fertilizer treatment alone, especially in sandy soils.

Economic Benefits of Balanced Nutrient Management

The initial negative gross margins for all treatments with fertilizer in the DSS reflected a low yield response to N and manure application (**Table 2**). This indicated a clear disincentive for famers to target nutrient resources to DSS. Despite the low soil fertility status, the gross margins were positive in the DCS, highlighting better prospects for targeting nutrient resources to DCS for improved productivity.

Gross margins with manure + fertilizer N application were far greater than the margins with fertilizer application alone, especially in depleted soils after nine seasons (**Table 2**). Although the use of manure (15 t/ha) in combination with 100 kg N/ha was the most profitable, the cost was more than double the investment cost in the optimum fertilizer treatment. This coupled with the generally small quantities of manure available to smallholder farmers could be a barrier to the benefits reported here. A regional program to supply fertilizers with N, P_2O_5 and K_2O would likely be of greater benefit to smallholder farmers on sandy soils. Nevertheless, the results showed clearly the need for improved targeting of balanced nutrient management strategies for increased profitability of crop production in the highly variable soil fertility conditions on smallholder farms (Wairegi and van Asten, 2010).

Summary

Maize yields and yield responses to fertilizer and manure application varied depending on soil type and management history. Productivity was very poor on a depleted sandy soil and gross margins for manure and fertilizer application were low, highlighting challenges for increasing productivity in degraded soils that cover large areas of croplands in sub-Saharan Africa. Multi-nutrient fertilizer application led to great increases in maize yields over N alone. However, in situations where K was not applied and crop residues removed, the highest attainable yields and gross margins in the long-term were achieved with a combined application of fertilization N and manure. BC

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