# Soil Organic Matter Regulates Maize Productivity and Fertilizer Response in Maize Production

By Shamie Zingore and Samuel Njoroge

Resource-constrained systems need strategies that focus on striking a balance between maintaining SOC above a critical value to ensure high agronomic fertilizer use efficiency and avoiding accumulation of nutrients to levels that prevent viable nutrient use efficiency.

Large agricultural areas in sub-Saharan Africa (SSA) are covered by inherently poor soils that have been subjected to soil fertility depletion and land degradation for many decades due to poor management, including low nutrient and organic matter application (Van der Velde et al., 2014). It is estimated that more than 60% of the arable land in SSA is degraded, with critically low contents of soil organic matter (SOM) (Bationo and Fening, 2018). Under these conditions, increased use and judicious management of fertilizer and organic nutrient resources are essential to optimize crop productivity and fertilizer use efficiency.

The status of SOM varies substantially in cropping fields, driven by differences in management practices, soil types, and landscape position (Tittonell et al., 2013; Zingore et al., 2007). Here we examine the critical role of SOM in regulating maize productivity and fertilizer use efficiency in smallholder farming systems, and provide insights for improved targeting of fertilizer resources to optimize maize productivity, based on two case studies in East and Southern Africa.

## Fertilizer response and agronomic N use efficiency patterns

Agronomic fertilizer use efficiency is intricately related to soil quality. Conceptually, the relationship between soil organic carbon (SOC), used as a proxy for soil quality, and crop yields and agronomic nitrogen use efficiency (AEN), creates three categories of response that can form the basis of optimizing fertilizer management (Musingizi et al., 2013):

**Category 1. Non-responsive degraded soil:** At the lower end of the SOC spectrum, low AEN is associated with very low SOC levels due to complex chemical, physical and biological constraints that severely constrain fertilizer response.

**Category 2. Responsive soils:** At moderate levels of SOC, high AEN are a result of nutrient deficiencies in the absence of other severe constraints.

**Category 3. Non-responsive fertile soils:** Very high SOC levels


Due to its strong influence on soil biological, chemical and physical properties and crucial soil functions, SOM is an essential indicator of soil quality with direct implications for crop productivity, food security, and human livelihood result in high N mineralization rates and sufficient soil N supply to achieve attainable yields. Soils in the 'non-responsive fertile' category are not common in smallholder farming systems in SSA. They are only found in small hot spots of nutrient accumulation in fields that receive high amounts of organic resources and fertilizer.

For resource-constrained systems, strategies for nutrient management optimization should focus on striking a balance between maintaining SOC above a critical value to ensure high agronomic fertilizer use efficiency while avoiding concentration of nutrient resources to levels that prevent viable nutrient use efficiency. The following case studies illustrate the association of SOC with maize fertilizer response in smallholder farming systems in SSA.

**Table 1.** Nitrogen and phosphorus agronomic efficiencies as influenced by nutrient management and SOC content, Wedza district, Zimbabwe.

| | | AEN | | | AEP | | |
|---|---|---|---|---|---|---|---|
| Site | SOC | NK | NPS | NPKS | NPS | PKS | NPKS |
| | (g $kg^{-1}$) | kg grain $kg^{-1}$ N applied | | | kg grain $kg^{-1}$ P applied | | |
| Site 1 | 3.5 | 7.0 | 16.0 | 17.0 | 31.5 | 2.0 | 35.5 |
| Site 2 | 5.4 | 12.1 | 35.2 | 31.4 | 51.8 | 13.3 | 51.4 |
| Site 3 | 8.9 | 14.1 | 29.9 | 36.3 | 50.5 | 14.1 | 52.4 |

> Critically low SOC levels characterize large areas of agricultural soils in SSA due to the predominance of coarse-textured soils and continuous cultivation with little additions of inorganic and organic nutrient resources.

## Case Study 1: Sandy soils in Zimbabwe

The Zimbabwean agricultural landscape is dominated by infertile sandy soils derived from granitic parent material. Steep soil fertility gradients on these sandy soils develop due to differentials in soil fertility management, particularly the variable application of manure. Some soils have degraded to a point where strategic targeting of scarce nutrient resources by smallholder farmers on different field types becomes crucial to ensure viable fertilizer use efficiencies.

To assess fertilization strategies for optimizing crop productivity and NUE in maize production on heterogeneous sandy soils under rain-fed conditions in Zimbabwe, Kurwakumire et al. (2014) established a nutrient omission study during two cropping seasons, across three on-farm sites with SOC ranging from 0.35–0.89%. N and P fertilizer agronomic efficiencies were influenced by both nutrient management and initial soil fertility (**Table 1**). Overall, this study established that fertilizer application was only agronomically and economically viable for soils with SOC > 0.44%.

In a related study under similar soil and agroecological conditions, Kafesu et al. (2017) showed similar trends of yield responses and fertilizer use efficiency. Baseline yields (< 1 t $ha^{-1}$) and attainable yields (< 2 t $ha^{-1}$) were low in fields with less than 0.4% SOC (**Fig. 1a, b**), which translated into very low AEN (**Fig. 1c**). Small increases in SOC between 0.4–0.6% resulted in more then 100% increases in baseline yields, attainable yields, and AEN. These results highlight the vital connection between SOC, land degradation, and crop productivity in granitic sandy soils with critical SOC values between 0.4–0.5%.

## Case Study 2: Clayey soils in Kenya

On-farm nutrient omission trials conducted over six consecutive cropping seasons in western Kenya allowed the assessment of initial field SOC status on spatial-temporal patterns in yield response to fertilizer N applications (Njoroge et al., 2017).

Fields in this study differed in past manure application history and initial SOC status (**Fig. 2**). SOC contents were generally between 1.5–2.5%, except for one field without past manure application that had SOC contents < 1%, and another field

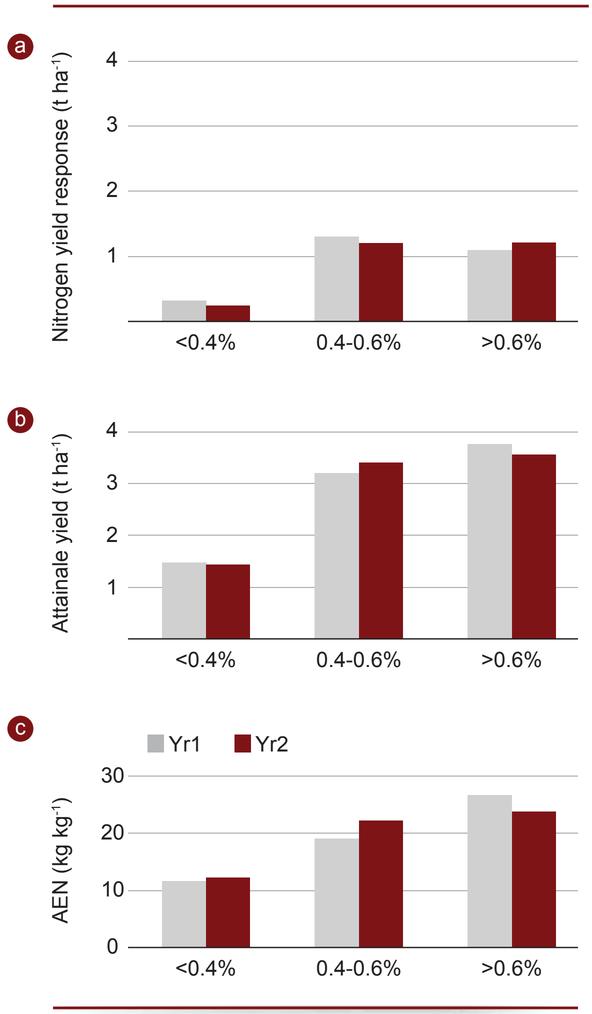


**Figure 1.** Baseline yield, attainable yields, and agronomic nitrogen use efficiencies for soil organic carbon ranges on a granitic sandy soil in Zimbabwe.

with manure applied in the past with SOC contents > 2.5% (**Fig. 2**). In the first three cropping seasons, yield responses to N were small in fields with SOC contents > 2%, while responses in fields with SOC contents between 1.5–2% were larger but highly variable (**Fig. 2a, b and c**). However in the subsequent three cropping seasons, yield response to N in fields with initial SOC contents > 2% increased while responses in fields with initial SOC contents between 1.5–2% remained highly variable, though the variability declined in the last cropping season (**Fig. 2d, 2e and 2f**). In each season, the field with SOC contents < 1% showed a moderate yield response to N that was consistently less than half of the largest yield response recorded in a particular season (**Fig. 2a, 2b, 2c, 2d, 2e and 2f**).

The initial lower yield response to N fertilization in fields with starting SOC contents > 2% can be attributed to larger soil N supply in these fields. However, continuous cropping without fertilizer N application led to a decline in soil N supply, which resulted in the larger response to N in later seasons. This indicates the fragility of SOC and soil N supply in such fields. It further demonstrates that such fertile 'non-responsive' fields can rapidly lose this status if applications of organic resources and fertilizer N are stopped. Therefore, while such fields may initially only require moderate quantities of fertilizer N to enhance AEN, larger fertilizer N applications or the co-application of available organic resources with moderate amounts of fertilizer N may be needed to maintain soil fertility and improve AEN over time. The consistently lower yield response to N in the field with initial SOC contents < 1% reaffirms the constrained response to fertilizer N under very low SOC contents, which has been attributed to the presence of additional biophysical constraints. Such fields may therefore require targeted measures, such as the application of large quantities of high-quality organic resources to improve SOC contents and address biophysical constraints for enhancing yield responses to fertilizer N applications. Zingore et al. (2008) showed that regular applications of large amounts of animal manure were required to significantly increase SOC, pH, available P, base saturation and restore crop productivity in degraded fields. The large variability in yield response to N observed for fields with initial SOC contents ranging from 1.5–2% demonstrates the huge uncertainty in the expected yield response to N at moderate SOC contents as previously observed for case study 1.

## Summary

Critically low SOC levels characterize large areas of agricultural soils in SSA due to the predominance of coarse-textured soils and continuous cultivation with little additions of inorganic and organic nutrient resources. The close association of SOC with maize yields and agronomic N use efficiencies were evident in East and Southern Africa. Sandy soils in Zimbabwe with very low SOC levels (< 1%) were highly susceptible to degradation with a critical SOC level between 0.4–0.5%, below which the yields in control plots declined to less than 1 t ha$^{-1}$ and fertilizer use efficiencies were very poor. In Kenya, SOC contents ranged from 1–3%, with clear patterns

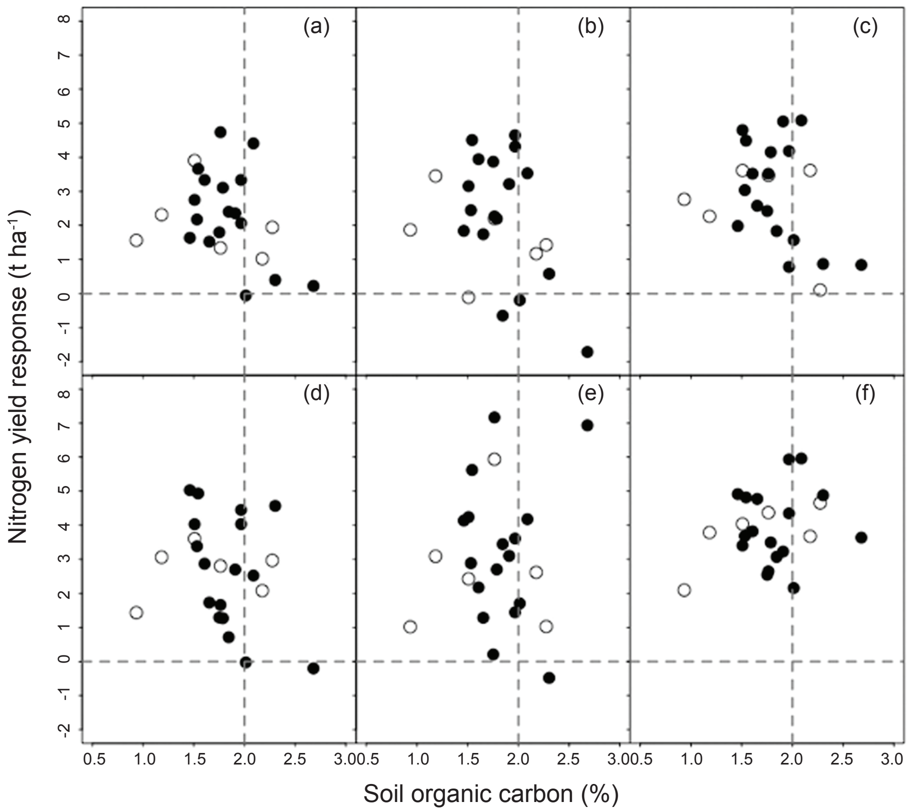


**Figure 2.** Temporal and spatial patterns in maize grain yield response to fertilizer N (t $ha^{-1}$) in on-farm trials (n=24) conducted across six consecutive seasons (long rainy season 2013 to short rainy season 2015), in fields differing in past manure applications in western Kenya. White circles represent fields without any farmer applying manure in the three seasons preceding the experiment. Black circles represent fields with some farmers applying manure within the three seasons preceding the experiment.

of degraded non-responsive soils with < 1.2% SOC, variable responses in mid-range SOC categories, and non-responsive fertile soils with high SOC soils (> 2%). ■

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## REFERENCES

Bationo, A., Fening, J.O. 2018. Soil Organic Carbon and Proper Fertilizer Recommendation, In: Bationo, A., Ngaradoum, D., Youl, S., Lompo, F., Fening, Joseph Opoku (Eds.), Improving the Profitability, Sustainability and Efficiency of Nutrients Through Site Specific Fertilizer Recommendations in West Africa Agro-Ecosystems: Volume 1. Springer International Publishing, Cham, pp. 1–10. https://doi.org/10.1007/978-3-319-58789-9_1

Kafesu, N., et al. 2018. Comparative fertilization effects on maize productivity under conservation and conventional tillage on sandy soils in a smallholder cropping system in Zimbabwe. Field Crop. Res. 218, 106–114.

Kurwakumire, N., et al. 2014. Maize productivity and nutrient and water use efficiencies across soil fertility domains on smallholder farms in Zimbabwe. Field Crop. Res. 164, 136–147.

Musinguzi, P., et al. 2013. Soil organic carbon thresholds and nitrogen management in tropical agroecosystems: concepts and prospects. Sustain. Dev. 6, 31-43.

Njoroge, S., et al. 2017. Strong spatial-temporal patterns in maize yield response to nutrient additions in African smallholder farms. Field Crop. Res. 214, 321–330.

Tittonell, P., et al. 2008. Yield gaps, nutrient use efficiencies and response to fertilisers by maize across heterogeneous smallholder farms of western Kenya. Plant Soil 313, 19–37.

Van der Velde, M., et al. 2014. African crop yield reductions due to increasingly unbalanced nitrogen and phosphorus consumption. Glob. Chang. Biol. 20, 1278–1288.

Zingore, S., et al. 2007. Soil type, management history and current resource allocation: Three dimensions regulating variability in crop productivity on African smallholder farms. Field Crop. Res. 101, 296–305.

Zingore, S., et al. 2008. Multiple benefits of manure: The key to maintenance of soil fertility and restoration of depleted sandy soils on African smallholder farms gradients on African smallholder farms. Nut. Cycl.Agroecosyst. 80, 267-282.