Soil Health constraints Contributing to Maize *(Zea Mays L.)* Yield Gap in Upper Tana Watershed of Murang'a County, Kenya

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Abstract

Small-scale farming in sub Saharan Africa is central to food security. However, subsistence farming is not yet meeting its role in reducing the current yield gaps and ensuring food security. Current agronomic recommendations are too broad to be useful and remain largely un-validated. Therefore, there is a growing demand for high precision information on soil conditions and agronomic performance to guide investment decisions on use of agro-inputs and other land management interventions. We collected 524 soil samples (0-20 and 20-50 cm depth ranges) to identify soil-health constraints for targeting interventions to improve maize production in Murunga County, Kenya. Our results showed that the soils in the study area were short of both macro (N, P, K) and micro (B, Zn, Mn, Cu) nutrients which – without substantial nutrient input - makes them marginally suitable for maize production. About 75% of the soils have pH values which are suitable for maize production while the remaining 25% are slightly acidic. Future management should consider maintaining the current pH level of most soils. DAP (18:46:0) and CAN (26:0:0) were the most widely applied fertilizers as basal and top-dressing applications, respectively. The current fertilizer application does not address the critically low potassium & Micro nutrient levels in the study area. About 78% of the top soils have a soil organic carbon value of less than 2%, indicating a need to apply more organic inputs.

Keywords: Soil health, Maize, Fertilizers, Land degradation, Crop production, Sustainable Intensification.

1. Introduction

It is projected that feeding the world population of 9.1 billion in 2050 would require food production as of 2005/7 to be increased by about 70%. Sub-Sahara Africa is the only region in the world with stagnant per capita food production (Muchena et al., 2005; Sanchez, 2002). Annual productivity increases of 4-7% are required if Africa were to rely on agriculture for economic development and food production (Tittonell and Giller, 2013).

Declining soil fertility as a result of little to no input and continuous cultivation have been cited as one of the major challenges to crop production (Tittonell and Giller, 2013). Large amounts of nutrients have been removed without replenishment over the past few decades. It has been estimated that average yearly depletion rates for N, P and K were at around 22, 2.5, and 15 kg/ha respectively in 37 African countries for the last 30 years (Sanchez, 2002). Soil degradation is progressively becoming more widespread in many parts of sub-Saharan Africa (SSA), and despite the importance of soil-health and agricultural productivity, stakeholders lack science-based spatial and contextual data that would inform soil and land management strategies (Takoutsing et al., 2016). Leveraging the site-specific biophysical information, understanding specific plant nutrition and evidence from the scientific literature could facilitate the attainment of a more comprehensive and effective crop fertilization program (Bindraban et al., 2015; Ichami et al., 2018).

Evaluation of potential and actual soil constraints using land assessment techniques provide ideas for suitable empirical land use options for the area and optimal specific requirement of a crop (Bera et al., 2017). The soil quality and its ability to sustain ecosystem services can be estimated by its functional properties, which are basically influenced by multiple physical and biochemical interactions (Takoutsing et al., 2018). Many soil property patterns in landscapes are complex (Scull et al., 2003), hence large sample sizes are essential in order to achieve reliable estimates required for soil status mapping.

Infrared spectroscopy has been developed as an alternative to the costly and time-consuming traditional methods for quantifying soil chemical and physical properties rapidly (Sila et al., 2017). The objective of this study was to evaluated soil health constraints for crop production to target input and management interventions.

2. Materials and Methods

2.1 Study site and farms

Muranga county lies between latitudes 0° 34' South and 10^0 7' South and longitudes 36° East and 37° 27' East. The average annual rainfall and mean annual temperature were 800 mm and 20 °C, respectively (Ministry Of Agricultre, 1987).

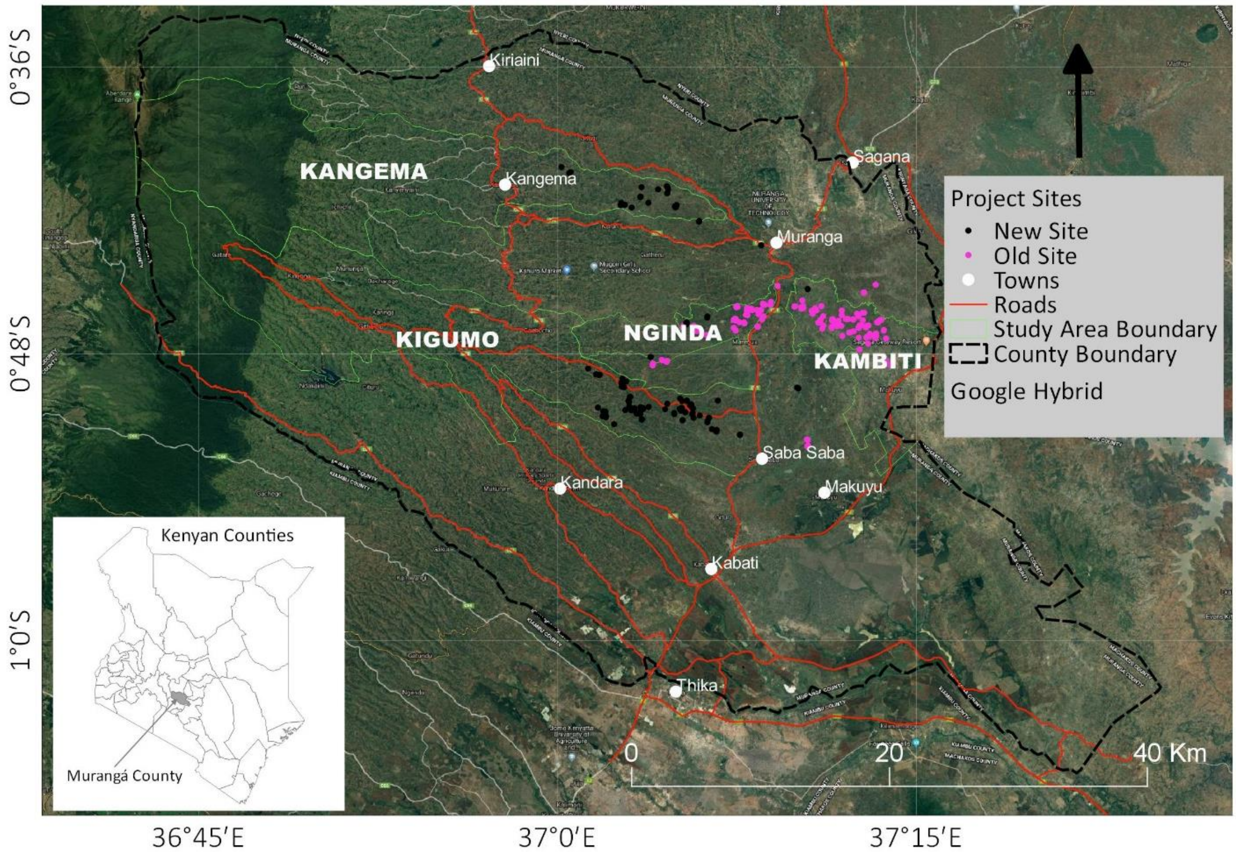

Figure 1: Location of the study area and locations where soil samples were collected, Muranga county, Kenya

2.2 Soil Sampling and Analysis

Soil samples were collected from 170. A composite of soils samples was collected from four sampling points on each farm. Samples were collected from 0-20 and 20-50 cm depth ranges. The samples were dried, crushed and sieved to pass 2 mm sieve. All samples were scanned using Mid-Infrared Spectrometer. Of which, 20% representative samples were selected for wet chemistry analysis. The wet chemistry data was used to calibrate and predict soil properties of the remaining 80% of the samples. Soil deficiency levels were calculated according to soil nutrient suitability levels of Naidu, L, G et al., 2006 and Africa Soil Information Service (AfSIS) values.

3.0 Results and Discussion

3.1 Soil physio-chemical properties

The physio-chemical properties are summarized in Table 1.

Table 1: Summary statistics of key soil properties for the top (0-20 cm) soil depth (n= 177)

Soil properties	Unit	Min	Max	Mean	Std Dev
N	%	0.09	0.23	0.15	0.03
P	ppm	1.64	28.03	6.69	4.2
K	ppm	54	1063	265	159
Ca	ppm	350	5658	1463	751
Mg	ppm	137	2093	508	289
Mn	ppm	49	489	262	85
Cu	mg/kg	1.5	8	5	1.4
B	mg/kg	0.3	1.0	0.5	0.1
Zn	mg/kg	0.6	27	4.5	2.7
pH		4.5	6.9	5.8	0.4
CEC	meq/100g	7.7	68	17	6.6
SOC	%	0.9	2.8	1.7	0.4

P = Phosphorus by Mehlich 3 extraction; K = Exchangeable potassium concentration by Mehlich 3 extraction; B = Boron by Mehlich 3 extraction; Zn = Total Zinc; Mn = Manganese by Mehlich 3 extraction.

There was no difference in the soil carbon and pH between the top (0-20 cm) and sub (20-50 cm) soils (Figure 2).

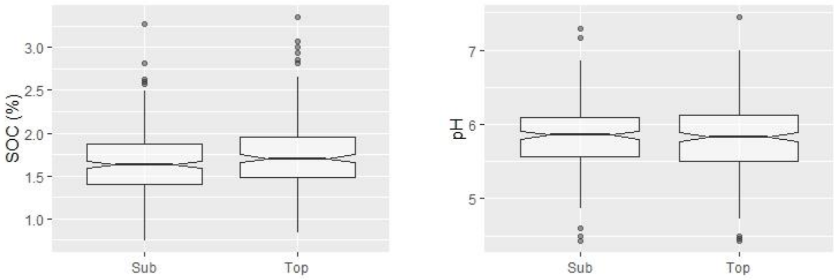

Figure 2: Boxplot showing SOC and pH values for the top (0-20 cm) and sub (20-50 cm) soil depths

Figure 3 showed density plots for selected soil properties in the sub-counties.

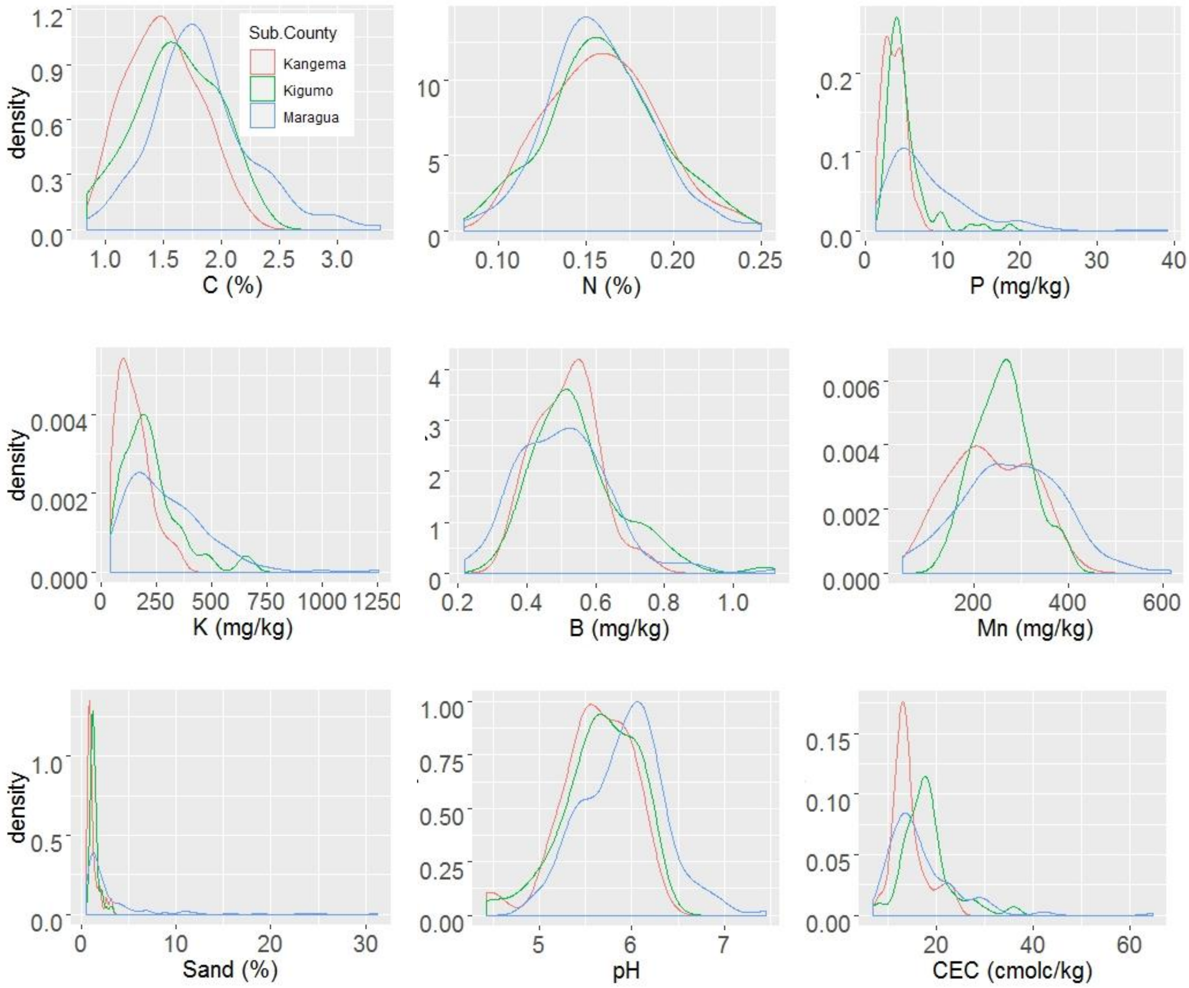

Figure 3: Density plots for SOC, N, P, K, B, Mn, Sand, pH and CEC soil properties in the three sub-counties

3.2 Soil Health Constraints for Crop Production

The soil results revealed that there are low levels of macro and micro nutrients. This is believed to affect crop yield in the study area. Kihara and Njoroge (2013), for example, reported that omission of P and N result in a 50% and 43% reduction in yield, respectively, relative to a full NPK treatment. There was N, P, and K gaps of 5%, 109 mg/kg, and 283 mg/kg, respectively (Table 2). Cu, B, Mn, and Zn gaps were by 10 mg/kg, 2 mg/kg, 15 mg/kg, and 110 mg/kg, respectively. About 78% of the farms had organic carbon levels below 2%. Such low level SOC value affects the soil chemical, physical, and biological properties (Oldfield et al., 2019).

Table 2: ***Nutrient gaps identified in the study area. The gaps were identified by using the moderately suitable soil nutrient ranges for maize as a reference.***

		Moderately suitable rages			**Results summary**			**Nutrient gap**
	Units	**Lower limit**	**Upper Limit**	**Average**	**Lowest**	**Highest**	**Average**	
Macronutrients								
Nitrogen	%	0.1	0.5	0.3	0.07	0.25	0.15	Low (-0.12)
Phosphorus	mg/kg	80	150	115	1.1	39	5.12	Low (-110)
Potassium	mg/kg	90	900	495	21.22	1251.87	211.5	Low (-284)
Micronutrients								
Copper	mg/kg	0.5	30	15.3	1.33	8.53	5.205	Low (-10)
Boron	mg/kg	0.5	4	2.3	0.17	1.13	0.51	Low (-2)
Manganese	mg/kg	60	500	280	40.68	616.81	264.635	Low (-15)
Zinc	mg/kg	10	20	15	0.43	39.37	3.89	Low (-11)

The soil results were compared to critical level as indicated in (Naidu, L, G et al., 2006) and AfSIS technical (Figure 4).

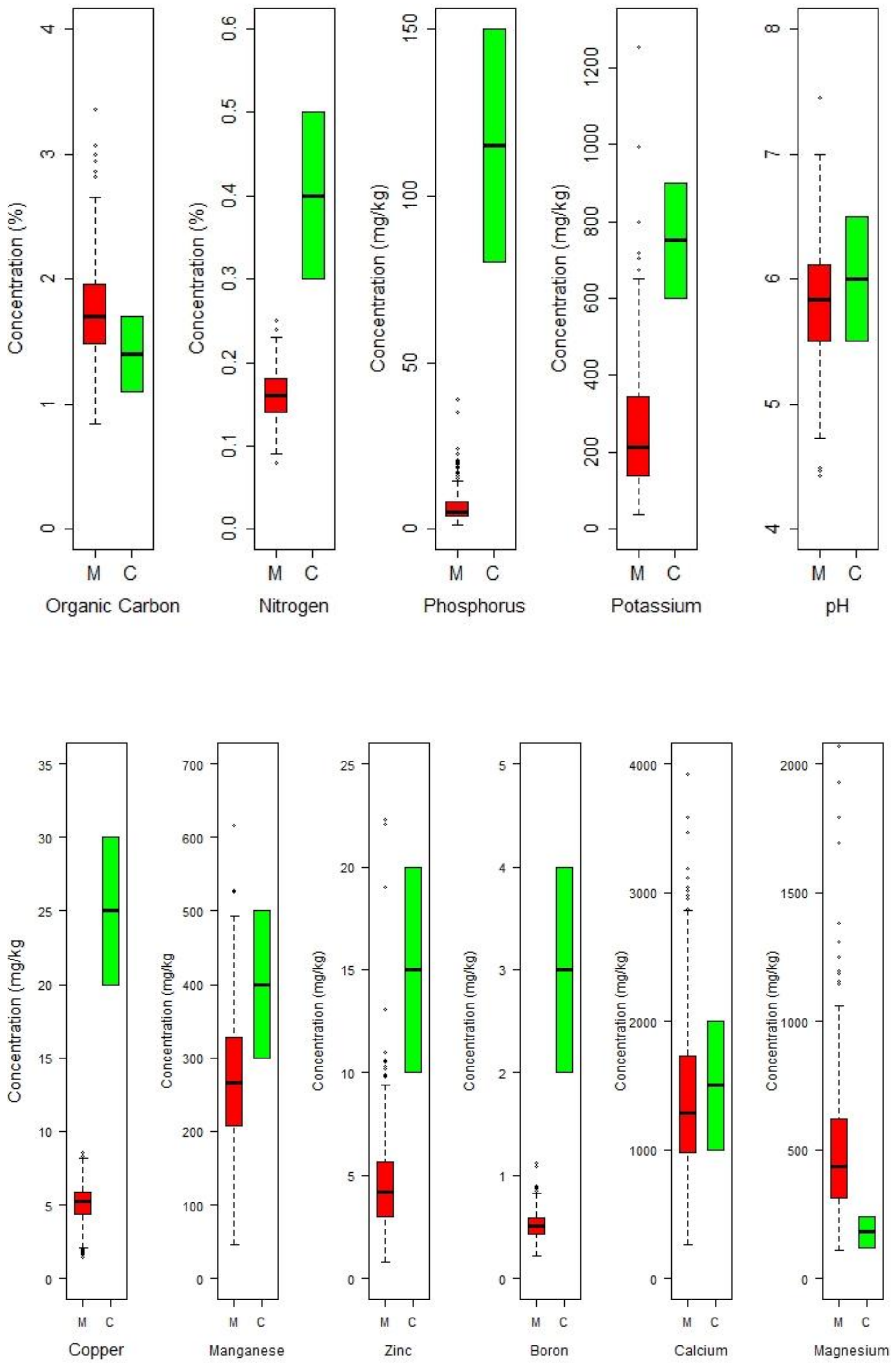

Figure 4: Muranga site soil nutrient parameters (M) compared to moderately suitable levels (C) based on Naidu 2006 and AfSIS suitability classes

3.3 Interventions to improve soil health constraints

3.3.1 Farm management

3.3.1.1 Manure

We found soil carbon significantly correlated with macro and micro-nutrients thus increasing the soil carbon level thought sustainable land management practices like application of manure and agroforestry interventions is important to improve crop response to fertilizers. Water availability could be constraint to crop production in the study area where agriculture was rain-fed. A study in Nigeria and Zambia reported that intercropping cereals with legume trees and supplementation with inorganic fertilizer can increase rain use efficiency and yield stability in rain-fed agricultural systems (Sileshi et al., 2011).

Mulching, if adopted, would be very helpful in reducing evaporation and enhancing soil fertility at the same time. Mulching has many benefits such as; protecting the soil against erosion, conserving moisture, maintaining the soil temperature and prevents weed growth. The most effective mulch is the organic mulch because it enhances the soil fertility after decomposition. It also enhances the soil structure and encourages the development of soil organisms.

3.3.1.2 Fertilizer application

It is important to identify non-responsive soils before fertilizer recommendations. According to Ichami et al. (2019), soil pH, exchangeable K, P-Olsen, total C, silt and average rainfall during a growing season were the significant predictors of variation in fertilizer response in Kenya. Non- responsiveness of poor soils is often related to low soil organic matter content (Tittonell and Giller, 2013), causing soil physical constraints (low water-holding capacity), low micronutrient availability (Kihara et al., 2017) and low microbial activity.

Only less than 10% of the soils in the study area fall under the non-responsive soil categories (soil carbon less than 1.1%; Ichami et al., 2019) soil carbon level of less than 1.1%. The obvious fertility gaps occur due in the absence of micronutrients in the available fertilizer. Yield can be increased by use of fortified NPK, CAN inorganic fertilizes or by blending fertilizers to incorporate S, Zn, Cu, Fe, Mn, B, and MO nutrients which are required for plant growth at different stages.

4.0 Conclusion and recommendations

Our results showed that the soils in the study area were short of both macro (N, P, K) and micro (B, Zn, Mn, Cu) nutrients which makes them marginally suitable for maize production. We found soil carbon significantly correlated with macro and micro-nutrients thus increasing the soil carbon level thought sustainable land management practices like application of manure and agroforestry interventions is important to improve crop response to fertilizers.

SOC can be increased by encouraging farmers to enhance plant residues and root inputs into soils and to increase the quantity of organic matter inputs such as manure and compost to the soil (from on/off farm). To conserve and regenerate productive soils in sites, there is need to build and maintain soil organic matter (SOM). Other management interventions will include limiting tillage operations to the minimum needed for adequate seed bed preparation and weed control and crop rotation using high residue crops.

Fertilizers amendments can be used to replenish the low levels. The farms that had soils with pH < 5.5, will require liming or organic material like crop residue application. Future management should consider maintaining the current pH level of most soils. The most important management interventions are therefore to replenish the soil nitrogen phosphorus and potassium content and micronutrients such as boron, zinc and copper.

Preserve, manage and build up soil organic matter content through recycling of crop residue and use of farmyard and compost manure. In these agroforestry technology fits very well. Fertilizer containing N, P an K which are fortified with micronutrients e.g. boron and zinc should be applied to supplement what is available in the soil. Micronutrient blended fertilizers e.g., Mavuno from Athi River Mining are some sources for increasing micronutrient contents.

We further recommend

1) To study soil nutrient budget in the maize and other crop production system over a longer period. We also recommend implementing of on-farm crop response studies to screen the various soil nutrient enhancement options to match local contexts and determine the attainable maize grain response to and potential of profitability ago-inputs.
2) We also observed information gaps in maize nutrient requirements, critical limits and suitability grading. Similarly, literature on the critical nutrient values or sufficiency ranges for maize leaves/tissue are also lacking in Africa that future researches should consider addressing these gaps.
3) To minimizing production losses and moving farmers towards more sustainable production should be a priority management intervention. When implementing technologies to reduce yield gaps, implementers should make due consideration for the technology's labour requirements, the farmers' financial ability and the farmers' management practices. Therefore, it is important develop the capacity of farmers on proper farm management practices particularly on conservational tillage practices and on weeding.

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