

This discussion paper is/has been under review for the journal Solid Earth (SE).
Please refer to the corresponding final paper in SE if available.

Precision of farmer based fertility ratings and soil organic carbon for crop production on a Ferralsol

P. Musinguzi¹, P. Ebanyat^{1,2}, J. S. Tenywa¹, T. A. Basamba¹, M. M. Tenywa¹, and D. Mubiru³

¹Department of Agricultural Production, Makerere University, P.O. Box 7062, Kampala, Uganda

²IITA-Uganda, Plot 15 East Naguru Road, P.O. Box 7878, Kampala, Uganda

³National Agricultural Research Laboratories, Kawanda, P.O. Box 7064, Kampala, Uganda

Received: 2 February 2015 – Accepted: 4 February 2015 – Published: 31 March 2015

Correspondence to: P. Musinguzi (musipato@yahoo.com)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Abstract

Simple and affordable soil fertility ratings are essential, particularly for the resource-constrained farmers in sub-Saharan Africa (SSA) in planning and implementing prudent interventions. A study was conducted on Ferralsols in Uganda, to evaluate farmer-field-based soil fertility assessment procedures, hereafter referred to as farmer' field experiences (FFE), for ease of use (simplicity) and precision, against more formal scientific quantitative ratings using soil organic carbon (SQR-SOC). A total of 30 fields were investigated and rated using both approaches, as low, medium and high in terms of soil fertility, with maize as the test crop. Based on maize yield, both rating techniques were fairly precise in delineating soil fertility classes, though the FFE approach showed mixed responses. Soil organic carbon in the top soil (0–15 cm) was exceptionally influential, explaining > 70% in yield variance. Each unit rise in SOC concentration resulted in 966–1223 kg ha⁻¹ yield gain. The FFE approach was effective in identifying low fertility fields, which was coherent with the fields categorized as low (SOC < 1.2%). Beyond this level, its precision can be remarkably increased when supplemented with the SOC procedure.

1 Introduction

Soil fertility assessment is crucial for effective land resource management as well as ensuring sustainable agricultural productivity and environmental health (Andrews et al., 2004; African Fertilizer Summit, 2006). Most developed countries are privileged to possess comprehensive, sophisticated and easily accessible laboratory facilities for their farming communities. The reverse is true for the bulk of farming communities in sub-Saharan Africa, where soil degradation has reached unprecedented levels (African Agriculture Status Report, 2013), yet soil fertility assessment is nearly inconceivable, owing to limited, yet costly laboratory services available. Consequently, food insecurity and poverty levels are unmatched with worldwide statistics. More than

SED

7, 1237–1261, 2015

Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



80% of the soils in Africa have physical and chemical fertility limitations to viable agriculture (Lal, 2006). Soil fertility in small-holder farming systems in SSA has been characterized by heterogeneity, especially in continuously cultivated fields (Ebanyat, 2009; Tittonell et al., 2007) Therefore, availability of more effective farmer-based assessment procedures is imperative to be able to achieve prompt, cost effective and user-friendly results, culminating into effective land-use planning.

Several farmer-based soil productivity assessment techniques have been documented in the SSA; the main ones being; use of local farmer field experiences, with or without the support of experienced neighbors or front-line workers (Payton et al., 2003; Tesfahunegn et al., 2011); use of GIS technology with infrared spectroscopy for rapid soil analysis (Shepherd et al., 2003); use of soil test kits and use of visual plant deficiency symptoms for rapid fertility assessment (Sanginga and Woome, 2009). Simple soil fertility ratings using farmers' field experiences (FFE) seems to hold the greatest promise for predicting soil productivity based on reports from elsewhere (Karlton et al., 2013; Talawar and Rhoades, 1998; Tesfahunegn et al., 2011). The procedure is affordable, rapid and simple to use since it is based on community indigenous knowledge (Corbeels et al., 2000; Payton et al., 2003; Schoonmaker Freudenberger, 1994). However, this procedure still requires formal precision valuation and refinement against conventional scientific qualitative assessments if it is to achieve reproducible results and provide effective recommendations to guide soil fertility and judicious nutrient management for sustainable crop production.

Soil organic carbon (SOC) is a more modern, fairly reliable and yet field-based procedure (Carter et al., 2003; Lal, 2006) for assessing soil fertility and yield, which could be benchmarked for correlation studies designed for validating the FFE procedure. Its potential application as a single indicator (SOC) can save farmers colossal of sums of money, compared to complete soil fertility assessment which includes chemical (pH, SOC, active organic matter, electrical conductivity, total nitrogen, phosphorus and potassium); physical (texture, bulk density, soil depth and water holding capacity); biological (microbial biomass, mineralisable N, specific

SED

7, 1237–1261, 2015

Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



respiration and macro-organisms) datasets (Doran and Parkin, 1996). The theoretical basis for SOC is that its high concentration is often associated with high fertility and yield, and the contrary is true for soils with low concentrations (Ebanyat, 2009; Mtambanengwe and Mapfumo, 2005; Musinguzi et al., 2013; Zingore et al., 2007).

5 However, some scientists have contested the exclusive adequacy of SOC for the characterization of soil fertility, particularly based on crop yield (Tittonell et al., 2008). These schools of thought notwithstanding, there is a general consensus that the SOC technique is wholesome in integrating physical, chemical and biological processes in the soil (Carter, 2002); thus having an edge over the alternative soil fertility assessment
10 procedures. Nonetheless, information on its precision in assessing soil fertility remains very scanty and debatable, particularly on its contribution to subsequent yield variance under soil conditions that are non-limiting in phosphorus and potassium. The objective of this study was to assess the reliability of the FFE and SQR-SOC procedures as instruments for soil fertility rating and yield prediction on a Ferralsol.

2 Materials and method

2.1 Study area and research approach

This study was conducted in Lwamata sub-county, Kiboga district in Central Uganda, in a Wooden Savanna agro-ecological zone (Wortmann and Eledu, 1999). The area is located at 1100–1400 m a.s.l., with a mean annual temperature of about 25 °C. Total
20 annual rainfall ranges from about 1000–1400 mm, and is distributed in a bi-modal pattern (Fig. 1). Soils in this area are classified as Ferralsol (IUSS Working Group, 2006), characterized by many soil fertility limitations.

The study involved two parishes, namely, Ssinde and Buninga, selected through farmers and other stakeholder consensus. The sites in Ssinde and Buninga
25 have altitude ranging 1206–1250 and 1113–1158 m a.s.l., respectively. They lie at 0°53′02.33″ N 31°50′12.48″ E for Ssinde and 0°54′41.55″ N, 31°49′52.52″ E for

Buninga. In Ssinde parish, Lwamirindo and Kagererekamu villages were selected while in Buninga parish, Kikalaala and Kigatansi villages were selected.

Using the FFE approach, farmers used experiences on soil and crop performance to score fields with different soil fertility ratings (Tesfaye et al., 2011). Together with the local farmer group leaders, a set of criteria was developed to identify farmers with land suitable for the study. The criteria included willingness to provide land for the study, household leaders of not less than 40 years old, and with working experience on soil fertility issues. Farmers aged 40 years and above were believed to have experience in identifying poor and good fields. Local leaders in each village made a list of 15 farmers with fields of low, medium and high fertility. From this list, only 8 farmers were randomly selected from the stratified fertility categories. Consequently, a total of 32 farmers from the four villages were recommended and a formal meeting was held to introduce the profiles of the research effort. A consensus on the criteria for rating soil fertility was reached and fields were scored as low = 1, medium = 2 and high = 3, using the following criteria:

Low/poor fertility category. Field with one or more of the following conditions; low grain yields ($< 1000 \text{ kg ha}^{-1}$), stunted plants, nutrient deficiency symptoms, light colored and/or shallow soils, exposed sub-soil, poor tilth (compacted) and very low water holding capacity.

Medium fertility category. Fields with one or more of the following conditions; moderate maize grain yield (at least within the range of $1000\text{--}2000 \text{ kg ha}^{-1}$), moderate growth vigor, mild to no nutrient deficiency symptoms; slightly darkish and deep soils, moderate in tilth (less compacted), moderate water holding capacity and less evidence of erosion.

High/good fertility category. Fields with one or more of the following conditions; high maize grain yield ($> 2000 \text{ kg ha}^{-1}$), high biomass, high growth vigour, good health (dark green, tall, large plant parts), and with soil that is very dark coloured, deep, with good tilth (not compacted), high water holding capacity, and no evidence of erosion.

SED

7, 1237–1261, 2015

Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

Field rating for soil fertility was conducted by each farmer following the set criteria. Farmers identified an extra field (about 20m from season 1 fields) for the second season experiments and accordingly rated its fertility. On-site visits to each proposed farmer's field was made for ground truthing and initial sampling was done for quick laboratory tests for SOC and silt + clay, so as to guide the study within the Ferrallitic properties. Slope gradient was measured using a clinometer, while other field attributes such as slope position, land use and cultivation history were obtained by field observation and probing information from farmers. On average, about 80 % of high and medium fields were located in the middle slope position, and 60 % of low fertility fields were located on the upper slope position. Slope gradient in all fields measured 5–16 %. All fields were opened for cultivation in the last 20–40 years and are often prepared manually with a hand-hoe. After the ground truthing process and characterization, only 15 farmers were finally willing to continue with the research trials; 8 farmers (16 experimental fields) in Ssinde parish and 7 (14 experimental fields) in Buninga parish, making a total of 30 experimental fields for the two seasons. For FFE, a total of 14 fields were rated as high, 6 as medium and 10 as low in fertility.

The second approach to soil fertility rating was the Scientific quantitative rating with SOC (SQR-SOC). This included soil sampling, laboratory analysis and participatory fertility rating. Four soil sub-samples from each selected farmers' site were collected from 0–15 (upper soil layer – USL) and 15–30cm (lower soil layer – LSL) using an auger. The soil was thoroughly mixed and quarter-sampled prior to taking composite samples for laboratory analyses. Soil texture, pH, Bray 1 extractable P, and exchangeable bases (K^+ , Mg^{2+} , Ca^{2+} , Na^+) were determined (Anderson and Ingram, 1993; Okalebo et al., 2002). Soil organic carbon was determined using the wet combustion technique (Walkey and Black, 1934) while total nitrogen was determined using the Kjeldahl distillation and back-titration method, at Makerere University Soil and Plant analytical laboratory. Using SOC concentrations of the top soil (0–15 cm) obtained from the laboratory tests, soils were rated into low, medium and high fertility categories, on assertion that its role in determining nutrient and water holding capacity,

improving structure, drainage, aeration, tilth and overall soil health, is undisputable as a good surrogate for soil fertility (Carter et al., 2003; Vanlauwe et al., 2007). Soil organic carbon concentrations in all sampled field ranged from 0.75 to 2.45 %. These were categorized into < 1.2 % (low), 1.2–1.7 % (medium) and > 1.7 % SOC (high). The rating was done in reference to the national threshold value of 1.74 % SOC (3 % soil organic matter) which is recommended as the critical concentration for sustainable crop production in low-input tropical soils (Okalebo et al., 2002; Ssali and Vlek, 2002). An equal number of fields ($n = 10$) were rated under low, medium and high fertility.

Subsequently, a formal meeting was held with farmers and the SQR-SOC approach was introduced. Using SOC as a simple and affordable quantitative method, and its associated effects on the physical, chemical, biological soil conditions which affect nutrient and water availability was well explained to the farmers. A demonstration on using SOC concentrations to rate soil fertility was conducted with the farmers. The need to apply P and K fertilizer to ameliorate key fertility limitations in a Ferralsol was emphasized.

2.2 Field experimental lay out and management

Maize (Longe 5 variety), was grown for two cropping seasons (March–May long rains and September–November short rains of 2010), on 30 farmers' fields. Experiments were laid out in a factorial, with a “superimposed” split-plot type of arrangement in a randomized complete block design (RCBD) with farmers' fields as replicates. Each field, rated using FFE and SQR-SOC, was used as a replicate for each of the three categories of low, medium and high (Nokoe, 1992). For this study, we considered only the control plots without N application, but with P and K applications, although other sub-plots in the whole trial included nitrogen fertilizer treatments at rates of 25, 50 and 100 kg N ha⁻¹. Phosphorus (25 kg ha⁻¹) and K (60 kg ha⁻¹) fertilizers were sourced from Triple Super Phosphate and Muriate of Potash, respectively. Phosphorus fertilizer was applied wholly at planting, and it was placed in planting holes (localised placement) so as to ease access of the P fertilizer by the developing maize roots.

Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Precision of simple soil fertility rating approaches in predicting crop yieldP. Musinguzi et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

Potassium-based fertilizers were split applied at planting and after four weeks after planting, by surface broadcasting and incorporation into the soil with a hoe to a depth of approximately 5 cm. Sowing was done by hand and at about 6–8 cm soil depth at the recommended spacing of 75 cm inter-row and 25 cm intra-row, resulting in a population of about 53 300 plants ha⁻¹. Weeding was done twice during the growing period using a hand hoe. There was no evidence of pests and diseases and therefore no pesticides were applied. At the end of each of the seasons, the plants were harvested in six central rows, leaving one guard rows on either sides of each plot. Total biomass and grain yield were determined on a dry weight basis after sun drying for about 15 days. Grain and stover were sub-sampled and oven-dried at 70 °C. The oven-dried weight was later on used to adjust both the grain and stover yield to a water content of 140 g kg⁻¹. Differences in soil fertility rating under the two approaches formed the basis for comparing how maize yield responded, under P and K non-limiting conditions in a Ferralsol.

2.3 Data analysis

Using GenStat software (13th version), an exploratory analysis of soil parameters and yield data was initially conducted and variables checked for normality using the Shapiro–Wilk test. Parameters with value $p < 0.05$ were log-transformed with $\log(X + 1)$ before proceeding to the next statistical procedure. All soil properties categorized under the SQR-SOC approach in the USL and LSL were tested using Analysis of Variance (ANOVA) and each property was compared using LSD at 5 % level of significance. In order to cater for the random effects of farmers' sites, a linear mixed model, using GenStat Restricted Maximum likelihood (REML) algorithms directive was applied (Caliński et al., 2005). The RELM model was also preferred because of the imbalance in the number of replicates associated with each of the fertility rating approaches. It has robust prediction algorithm to analyse such unbalanced designs. For this study, only yield comparisons from the control (without N rates) were considered for each soil fertility rating approach. The Fixed model terms included the seasons, the fertility rating

Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



The RELM test for fixed effects demonstrated that both soil fertility ratings, that is, the FFE and SQR-SOC are reliable and can predict yield. Both approaches registered significant yield differences in the rated fields ($p < 0.05$). The seasons did not result in significant yield differences, whereas the interactions with each soil fertility rating method were significant. Grain yield was not significantly different in medium and high fertility under FFE (Table 2). Few farmers were competent in identifying medium fertility fields, but majority ably identified low and high soil fertility.

3.2 Reliability of SOC and selected soil parameters in predicting yield

The three PLS model (1st, 2nd and 3rd) components defined the direction of different soil properties that exhibited the greatest variations (Table 3). The three components (1st, 2nd and 3rd) registered SOC (77.2%), Mg^{2+} (75.5%) and clay (67.9%) in the top soil (0–15 cm), while the mean concentrations from 0–15 and 15–30 cm had high variations registered with both clay and silt (99%), Ca^{2+} (92.3) and SOC (72.2%). The last three components (6th, 7th and 8th) were associated with the least variations, much evident with pH and Na^+ . Soil organic carbon and clay were consistently influential in both soil layers. This was also reflected in the 1st, 2nd, and 3rd PLS components, that explained yield variance of 78.1% in the top soil and 71.9% for the mean concentrations, respectively.

Linear regression showed significant relationship among the different variables (biomass, grain yield and SOC concentrations) ($p < 0.05$). The linear model fittings explained grain yield variability due to SOC, which accounted for 60.21% in the top soil (Fig. 2). The linear regression fitted model resulted in 966 kg ha^{-1} yield-gain per unit increase in SOC for USL and about 1223 kg ha^{-1} yield-gain per unit increase in total SOC considering the MSL (Fig. 2). Similar trends were obtained for biomass, registering 3022 kg ha^{-1} gains in the top soil and 2971 kg ha^{-1} gain for mean concentrations, for every unit change in SOC.

4 Discussion

4.1 Yield patterns in fields rated using farmer field experiences and soil organic carbon

The soil properties in upper and lower soil layers agree with Ferrallitic properties (IUSS working group, 2006). Total SOC and N in both soil layers were consistently sufficient to pinpoint soil fertility categories and yield patterns perceived by the tropical farmers, although pH, Bray 1 extractable P, exchangeable K^+ , Ca^{2+} , and texture, varied little in the top soil (Table 1). In contrast, the lower soil layer exhibited change in the concentration pattern for the majority of parameters (pH, total N, Bray 1 extractable P, exchangeable K^+ , Ca^{2+} , Mg^{2+} and silt). This can be attributed to the selective transporting of fine materials, arising from continuous soil tillage or organic input applications. The small changes in clay and silt content with soil fertility express the typical nature of sandy loam Kaolinitic Ferralsols (IUSS Working Group, 2006). The influence of SOC on soil properties appeared strong in the lower soil depth, which clearly denotes it as a critical factor in explaining field heterogeneity reported in tropical soils (Ebanyat, 2009; Tittonell et al., 2008). The concurrent increase in clay and SOC with fertility agrees with findings by Feller and Beare (1997), who also reported a positive relationship between clay content and SOC for soil with low activity clay, basically due to increased adsorption sites on the clay mineral surface. Our results illustrate the importance of SOC in influencing soil functions and chemical fertility, notwithstanding the inherently low Bray 1 extractable P and pH associated with Ferralsols. This provides a benchmark to reflect on simple rating options that are feasible for farmers.

The significant yield differences in soil fertility rating approaches (FFE and SQR-SOC) is a promising insight to improving the challenges of soil fertility management among resource constrained small-scale farmers (Table 2). Soil fertility corroborated with maize grain yield, irrespective of the rating approaches, suggesting that farmers can easily identify niches of soil fertility in their farms (Tittonell et al., 2007). The

Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



capacity of farmers to identify low fertility ascribes to the tendency of most tropical farmers to abandon fields that are believed to be unproductive and non-responsive (Tittonell and Giller, 2013). The poor yield response in fields of low fertility suggested that ideal soil organic carbon concentrations should not be below 1.2%, since this may be insufficient to support crop production in a favorable growing season (Fig. 1). The few farmers who rated medium fertility suggested some difficulty in clearly differentiating such fields from the good field (Table 2). However, it also showed that the six farmers were possibly more experienced and keen to the rating criterion that was developed. Conversely, this is also a precaution that over-reliance on the FFE approach can result in weak fertility judgment and inappropriate management interventions, and must be used with precaution. However, farmers' capacity to clearly differentiate low and high fertility fields cannot be underrated, and this is promising for rural land use policies geared towards soil fertility improvement. The maize yield trends indicated farmers' ability to correctly judge soil fertility, with or without scientifically based approaches. This agrees with findings in Ethiopia that observed farmers' ingenuity in predicting soil fertility status based on experiences on crop yields, indicator plants, soil color or even soil softness (Karlun et al., 2013; Tesfahunegn et al., 2014). For this study, positive complementarities between indigenous and scientific knowledge can be considered much more reliable in soil fertility rating to plan for measures to combat land degradation (Tefahunegn et al., 2011). Application of FFE using local knowledge alone is believed to be complex, multi-faceted with much experiential trial and error (Payton et al., 2003), and backing the farmer knowledge with simple quantifiable scientific indicators is important. The coherent ratings in low fertility fields in both approaches can be instrumental in easily guiding generalized fertilizer application and fertility restoration strategies (Bekunda et al., 2010; Musinguzi et al., 2014). The Integrated Soil Fertility Management approach, currently recommended in sub-Saharan Africa, need to be implemented in low fertility fields to boost crop productivity (Musinguzi et al., 2013; Vanlauwe and Zingore, 2011). For soils with medium and high fertility, the study suggests that farmers require scientific backing with SOC to overcome

Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



uncertainty in identifying such fields (Negatu and Parikh, 1999; Tesfahunegn et al., 2011). Although the FFE method is known to be rapid, simple, less costly, and with relatively acceptable efficiency (Tefahunegn et al., 2014), using SOC can increase benefits such as confidence and reliability among tropical farmers. However, other scientific approaches such as assessing nutrient status based upon the hierarchy of limiting nutrients should not be underestimated (Bekunda et al., 2010).

4.2 Reliability of SOC and selected soil properties in predicting yield

Soil organic carbon and clay were the most influential soil parameters resulting in the greatest variations in soil and yield in a Ferralsol (Table 3). The contribution of SOC and clay agrees with several studies that found close a relationship between SOC and clay content (Ebanyat, 2009; Feller and Beare, 1997). Total N was not so influential on yield, contrary to the significant correlation with soil fertility (Table 1), possibly because of the low mineralization potential associated with the soil, which depends on SOC for sustainable productivity (Tiessen et al., 1994). Although the focus of the study was on simple indicators, further analysis of C fractions such as particulate organic C would deepen the understanding of N cycling (Musinguzi et al., 2015). In the context of texture, considerable variances in clay and silt in the mean concentrations accounted for increased content with soil depth, possibly due to continuous cultivation that selectively move silt or clay into the lower layer (Derpsch, 2008). The increase in yield as influenced by SOC and clay was coherent with earlier studies (Tittonell et al., 2007). The findings present reasonably strong evidence on importance of SOC and texture in soil fertility rating, although further studies on how other soil parameters such as Al toxicity, micro-nutrients and other properties such as aggregation and structure can be explored. The 1st, 2nd, and 3rd PLS components explained the yield variance of 78.1 % in top soil and 71.9 % in the mean concentrations (Table 3), which again emphasized the consistence of SOC, among other soil properties, in yield prediction irrespective of soil depth. The top soil and mean concentrations from the top and lower soil layers resulted in high yield variance, indicating that both can reliably be

Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



used in assessing soil fertility. Although Okalebo et al. (2002) recommends sampling at a uniform depth of 0–15 or 0–20 cm, sampling to as deep as 0–30 cm expressed fertility variability, and this could be better than relying on the top soil alone in field heterogeneity assessment studies for maize production. Perceptions of farmers about soil fertility “niches” and yield could be boosted with simple scientific options at an appropriate depth, although there are assertions that the identification of main nutrient limitations to productivity have remained abstract to farmers (Tittonell et al., 2005).

High maize grain yield gains of 966 kg ha^{-1} in the upper 0–15 cm, compared to 1223 kg ha^{-1} per unit change of SOC for mean SOC concentrations (0–15 and 15–30 cm) demonstrated the influence of soil depth in soil fertility and yield prediction. Mean concentrations of soil parameters registered high responsiveness and this may be attributed to the high levels of silt + clay and particulate organic matter, which influence nutrient availability and yield (Derpsch, 2008; Gregorich et al., 2006; Kapkiyai et al., 1999; Thompson et al., 1991). Although the use of organic carbon fractions is not affordable to resource constrained smallholder farmers, exploring their relative contributions to yield variability at different soil depth can be explored in future studies. In line with our data, similar trends of linear maize yield increase with SOC have been reported in Nigeria and Kenya (Kapkiyai et al., 1999; Lal, 1981). In a Kenyan Kikuyu clay soil (Humic Nitisol) and a Nigerian Alfisol, 243 and 254 kg ha^{-1} yield gains were registered, respectively. Interestingly, this study registered triple yield gains per unit change in SOC in a Ferralsol. Application of phosphorus and potassium fertilizers could have played a critical role to boost yield gains in a low P Ferralsol. Thus, high yield can be obtained in medium to high fertility fields with SOC > 1.2% without use of nitrogen fertilizers.

Soil organic carbon from the top soil and the mean concentrations from top and lower layers can be commended as good fertility indicators, although it is also apparent that the role of clay should not be ignored. For resource constrained farmers, testing one parameter such as SOC in top soil is commendable, as an affordable fertility assessment tool that can improve the decision making process to investing in soil

Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



management. The current cost of SOC analysis at the Makerere University's soils laboratory in Uganda, is about USD2.5, as compared to USD18.5 for the whole spectrum of what is termed routine analysis which includes up to 9 major soil parameters. As such, consideration of such a single indicator (SOC) can save a farmer colossal sums of money associated with soil fertility assessment. However, using SOC must consider other factors that led to unexplained yield variances. In case of significant anomalies evident on maize yield, detailed laboratory tests are inevitable.

5 Conclusions

Both the FFE and SQR-SOC soil fertility rating approaches consistently demonstrated high capacity to predict maize yields in a Ferralsol. However, soil fertility rating based on scientific quantitative rating with SOC showed clearer yield responses than the farmers' field experiences approach. The later evidently showed mixed ratings for medium and high soil fertility but both approaches corresponded well in rating poor soils. The top soil (0–15 cm) and mean concentrations of SOC from top (0–15 cm) and lower soil depth (15–30 cm) consistently influenced yield variations. Each unit increase in SOC concentration resulted in triple grain yield gains under P and K ameliorated soil conditions, which is higher than what is reported in other studies in Africa. Although most of the smallholder farmers cannot access phosphorus or even potassium, this study demonstrated the novelty of using SOC, which best applies under minimal nutrient limiting conditions. Using field experiences of resource poor farmers, coupled with simple but affordable scientific quantitative approaches such as SOC testing can enhance farmers' decision making in soil fertility improvement for maize production. Scientific parameters such SOC can provide farmers added benefits such as increased confidence, reliability and precision as compared to relying on experiences in soil fertility evaluation.

Acknowledgements. The authors thank the World Phosphate Institute (IMPHOS) for providing field research funds. We thank the farmers who availed us land to conduct the experiments. The authors would like to thank anonymous referees for a range of supportive and constructive comments that have helped improve this manuscript.

5 References

- African Agriculture Status Report: Focus on Staple Food Crops, Alliance for a Green Revolution in Africa, Alliance for a Green Revolution in Africa (AGRA), Nairobi, Kenya, 44–46, 2013.
- Anderson, J. and Ingram, J.: Tropical Soil Biology and Fertility: a Handbook of Methods, CAB International, Wallingford, 221 pp., 1993.
- 10 Andrews, S. S., Karlen, D. L., and Cambardella, C. A.: The soil management assessment framework, *Soil Sci. Soc. Am. J.*, 68, 1945–1962, doi:10.2136/sssaj2004.1945, 2004.
- Bekunda, M., Sanginga, N., and Woomer, P. L.: Restoring soil fertility in sub-Saharan Africa, *Adv. Agron.*, 108, 183–236, 2010.
- 15 Caliński, T., Czajka, S., Kaczmarek, Z., Krajewski, P., and Pilarczyk, W.: Analyzing multi-environment variety trials using randomization-derived mixed models, *Biometrics*, 61, 448–455, 2005.
- Carter, M. R.: Soil quality for sustainable land management, *Agron. J.*, 94, 38–47, 2002.
- Carter, M., Angers, D., Gregorich, E., and Bolinder, M.: Characterizing organic matter retention for surface soils in eastern Canada using density and particle size fractions, *Can. J. Soil Sci.*, 20 83, 11–23, doi:10.4141/S01-087, 2003.
- Corbeels, M., Shiferaw, A., and Haile, M.: Farmers' knowledge of soil fertility and local management strategies in Tigray, Ethiopia, IIED-Drylands Programme, December 2000.
- Derpsch, R.: No-tillage and conservation agriculture: a progress report, in: No-Till Farming Systems, edited by: Goddard, T., Zoenisch, M. A., Gan, Y. T., Ellis, W., Watson, A., and Sombatpanit, S., World Association of Soil and Water Conservation, Bangkok, 7–39, 2008.
- 25 Doran, J. W.: Soil health and global sustainability: translating science into practice, *Agr. Ecosyst. Environ.*, 88, 119–127, 2002.
- Ebanyat, P.: A Road to Food?, Efficacy of Nutrient Management Options Targeted to Heterogeneous Soils in the Teso Farming System, Uganda, PhD thesis, Wageningen University, Wageningen, 45–74, 2009.
- 30

Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Esposito Vinzi, V., Chin, W. W., Henseler, J., and Wang, H.: Handbook of Partial Least Squares: Concepts, Methods and Applications, Springer Handbooks of Computational Statistics, 850 pp., 2010.

Feller, C. and Beare, M.: Physical control of soil organic matter dynamics in the tropics, *Geoderma*, 79, 69–116, 1997.

Gregorich, E. G., Beare, M. H., McKim, U. F., and Skjemstad, J. O.: Chemical and biological characteristics of physically uncomplexed organic matter, *Soil Sci. Soc. Am. J.*, 70, 975–985, doi:10.2136/sssaj2005.0116, 2006.

African Fertilizer Summit: Africa Fertilizer Summit Proceedings, Abuja, Nigeria, 9–13 June, IFDC, Muscle Shoals, 182 pp. 2006.

IUSS Working Group WRB: World reference base for soil resources 2006, World Soil Resources Reports No. 103, FAO, Rome, 2006.

Kapkiyai, J. J., Karanja, N. K., Qureshi, J. N., Smithson, P. C., and Woomer, P. L.: Soil organic matter and nutrient dynamics in a Kenyan Nitisol under long-term fertilizer and organic input management, *Soil Biol. Biochem.*, 31, 1773–1782, 1999.

Karlton, E., Lemenih, M., and Tolera, M.: Comparing Farmers' perception of soil fertility change with soil properties and crop performance in Beseku, Ethiopia, *Land Degrad. Dev.*, 24, 228–235, doi:10.1002/ldr.1118, 2013.

Lal, R.: Soil erosion problems on Alfisols in western Nigeria, VI. Effects of erosion on experimental plots, *Geoderma*, 25, 215–230, doi:10.1016/0016-7061(81)90037-9, 1981.

Lal, R.: Enhancing crop yields in the developing countries through restoration of the soil organic carbon pool in agricultural lands, *Land Degrad. Dev.*, 17, 197–209, doi:10.1002/ldr.696, 2006.

Mtambanengwe, F. and Mapfumo, P.: Organic matter management as an underlying cause for soil fertility gradients on smallholder farms in Zimbabwe, *Nutr. Cycl. Agroecosys.*, 73, 227–24, 2005.

Musinguzi, P., Tenywa, J. S., Ebanyat, P., Tenywa, M. M., Mubiru, N. D., Twaha, A. B., and Adrian, L.: Soil organic carbon thresholds and nitrogen management in tropical agroecosystems: concepts and prospects, *Journal of Sustainable Development*, 6, 31–43, doi:10.5539/jsd.v6n12p31, 2013.

Musinguzi, P., Ebanyat, P., Tenywa, J. S., Mwanjalolo, M., Basamba, T. A., Tenywa, M. M., and Porter, C.: Using DSSAT-CENTURY Model to simulate soil organic carbon dynamics under

Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



a low-input maize cropping system, *J. Agr. Sci.*, 6, 120–131, doi:10.5539/jas.v6n5p120, 2014.

Musinguzi, P., Tenywa, J. S., Ebanyat, P., Basamba, T. A., Tenywa, M. M., Mubiru, D. N., and Zinn, Y. L.: Soil organic fractions in cultivated and uncultivated Ferralsols in Uganda, *Geoderma Regional*, 4, 108–113, 2015.

Negatu, W. and Parikh, A.: The impact of perception and other factors on the adoption of agricultural technology in the Moret and Jiru Woreda (district) of Ethiopia, *Agr. Econ.*, 21, 205–216, doi:10.1016/S0169-5150(99)00020-1, 1999.

Nokoe, S.: Technical paper 7: Statistical and experimental design considerations in alley farming, in: *The AFNETA Alley Farming Training Manual*, edited by: Tripathi, B. R. and Psychas, P. J., International Livestock Centre for Africa, Addis Ababa, 1–34, 1992.

Okalebo, J., Gathua, K., and Woome, P.: *Laboratory Methods of Plant Soil Analysis: a Working Manual*, TSBF-UNESCO, Nairobi, 128 pp., 2002.

Payton, R., Barr, J., Martin, A., Sillitoe, P., Deckers, J., Gowing, J., Hatibu, N., Naseem, S., Tenywa, M., and Zuberi, M.: Contrasting approaches to integrating indigenous knowledge about soils and scientific soil survey in East Africa and Bangladesh, *Geoderma*, 111, 355–386, doi:10.1016/S0016-7061(02)00272-0, 2003.

Sanginga, N. and Woome, P. L. (Eds.): *Integrated Soil Fertility Management in Africa: Principles, Practices, and Developmental Process*, Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture, Nairobi, Kenya, 263 pp., 2009.

Schoonmaker Freudenberg, K.: *Challenges in the Collection and Use of Information on Livelihood Strategies and Natural Resource Management, Beyond Farmer First*, London, Intermediate, 1994.

Ssali, H.: Soil organic matter and its relationship to soil fertility changes in Uganda, in: *Policies For Improved Land Management in Uganda*, edited by: Nkonya, E. M., Sserunkuuma, D., and Pender, J., 2nd National Workshop, 24–26 April 2002, International Food Policy Research Institute, Washington DC, 99–102, 2002.

Talwar, S. and Rhoades, R. E.: Scientific and local classification and management of soils, *Agr. Hum. Values*, 15, 3–14, doi:10.1023/A:1007497521205, 1998.

Tesfahunegn, G. B., Tamene, L., and Vlek, P. L.: A participatory soil quality assessment in Northern Ethiopia's Mai-Negus catchment, *Catena*, 86, 1–13, doi:10.1016/j.catena.2011.01.013, 2011.

Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Tesfahunegn, G. B., Tamene, L., Vlek, P. L., and Mekonnen, K.: Assessing farmers' knowledge of weed species, crop type and soil management practices in relation to soil quality status in Mai-Negus Catchment, Northern Ethiopia, *Land Degrad. Dev.*, doi:10.1002/ldr.2233, online first, 2014.

5 Tesfaye, A., Githiri, M., Derera, J., and Debele, T.: Subsistence farmers' experience and perception about the soil, and fertilizer use in Western Ethiopia, *Ethiopian Journal of Applied Sciences and Technology (EJAST)*, 2, 61–74, 2011.

Thompson, A., Gantzer, C., and Anderson, S.: Topsoil depth, fertility, water management, and weather influences on yield, *Soil Sci. Soc. Am. J.*, 55, 1085–1091, doi:10.2136/sssaj1991.03615995005500040032x, 1991.

10 Tiessen, H., Cuevas, E., and Chacon, P.: The role of soil organic matter in sustaining soil fertility, *Nature*, 371, 783–785, 1994.

Tittonell, P. and Giller, K. E.: When yield gaps are poverty traps: the paradigm of ecological intensification in African smallholder agriculture, *Field Crop. Res.*, 143, 76–90, 2013.

15 Tittonell, P., Vanlauwe, B., Leffelaar, P., Rowe, E., and Giller, K.: Exploring diversity in soil fertility management of smallholder farms of western Kenya, heterogeneity at region and farm scales, *Agr. Ecosyst. Environ.*, 110, 149–165, 2005.

Tittonell, P., Vanlauwe, B., De Ridder, N., and Giller, K. E.: Heterogeneity of crop productivity and resource use efficiency within smallholder Kenyan farms: soil fertility gradients or management intensity gradients?, *Agr. Syst.*, 94, 376–390, doi:10.1016/j.agsy.2006.10.012, 2007.

20 Tittonell, P., Shepherd, K. D., Vanlauwe, B., and Giller, K. E.: Unravelling the effects of soil and crop management on maize productivity in smallholder agricultural systems of western Kenya – An application of classification and regression tree analysis, *Agr. Ecosyst. Environ.*, 123, 137–150, doi:10.1016/j.agee.2007.05.005, 2008.

25 Vanlauwe, B. and Zingore, S.: Integrated soil fertility management: An operational definition and consequences for implementation and dissemination, *Better Crops*, 95, 4 pp., 2011.

Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R., and Six, J.: Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management, *Plant Soil*, 339, 35–50, doi:10.1007/s11104-010-0462-7, 2011.

30 Walkley, A. and Black, I. A.: An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method, *Soil Sci.*, 37, 29–37, doi:10.1097/00010694-193401000-00003, 1934.

Wortmann, C. S. and Eledu, C. A.: Uganda's Agro Ecological Zones: A Guide For Planners and Policy Makers, CIAT, Kampala, Uganda, 1999.

Zingore, S., Murwira, H., Delve, R., and Giller, K.: Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe, Agr. Ecosyst. Environ., 119, 112–126, 2007.

SED

7, 1237–1261, 2015

Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Table 1. Mean values of soil properties in 0–15 and 15–30 cm soil depths for soil fertility categories derived using SOC; low fertility (< 1.2% SOC), medium fertility (1.2–1.7% SOC) and high SOC (> 1.7%) for 30 sampled fields ($n = 10$ for each category) of a Ferralsol in Uganda.

	pH (H ₂ O)	Total SOC	Total N	Extractable P (Bray 1)	K ⁺	Na	Extractable Ca ²⁺ Mg ²⁺		Silt	Clay
		%		mg kg ⁻¹		cmol(+) kg ⁻¹ soil		%		
0–15 cm										
Low fertility	5.54	0.98	0.14	5.3	0.22	0.073	3.89	1.43	12.5	21
Medium fertility	5.41	1.39	0.19	9.5	0.22	0.101	4.61	1.46	17.6	22
High fertility	5.72	1.94	0.20	11.3	0.34	0.106	5.01	1.94	16.8	24
LSD at 5%	0.31	0.16	0.03	6.38	0.15	0.03	1.24	0.19	5.84	7.8
15–30 cm										
Low fertility	5.42	1.12	0.10	4.32	0.19	0.080	4.11	1.42	13.6	21
Medium fertility	5.54	1.41	0.12	8.34	0.33	0.103	4.98	2.01	18.1	24
High fertility	5.72	2.11	0.24	12.5	0.38	0.105	5.62	2.14	19.9	26
LSD at 5%	0.24	0.22	0.06	4.91	0.17	0.026	1.22	0.27	5.41	5.11

LSD = least significant difference for comparing means.

Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Table 2. Grain and biomass yield in differently rated fields using the farmers' field experiences and scientific quantitative rating with SOC approaches in a Ferralsol in Uganda.

Rating approaches	Soil fertility ratings ($N = 30$)	Number of fields scored	Grain yield	Biomass yield
			kg ha ⁻¹	
Farmer' field experiences (FFE)	Low	10	1113	6713
	Medium	6	1675	8556
	High	14	2042	8994
	LSD at 5%		369	1012
Scientific quantitative rating with SOC (SQR-SOC)				
	Low (< 1.2% SOC)	10	1115	6121
	Medium (1.2–1.7% SOC)	10	1554	7421
	High (> 1.7% SOC)	10	2284	8100
	LSD at 5%		244.3	1233

LSD = least significant difference at 5% level of significance.

Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

Table 3. Estimates of partial least square (PLS) percentage variances for soil parameters and maize grain yield for 0–15 cm and mean concentration of soil properties from 0–15 and 15–30 cm in a Ferralsol.

PLS components	% of explained variance in grain yield							
	1	2	3	4	5	6	7	8
0–15 cm	49.5	16.6	12	1.3	3.9	0.1	1.5	2.2
<i>Mean concentrations</i> (0–15 and 15–30)	67.3	2.6	2	1.3	3.5	0.4	1.9	0
% of explained variances in selected soil properties								
<i>Top soil</i> (0–15 cm)								
pH	4.4	9.3	9.4	2.2	63	11.7	0.0	0.0
Total SOC	9.1	68.1	10.1	6.8	0.4	5.5	0.0	0.0
Total N	5.8	51.7	4.3	7.8	3.6	10.0	15.5	1.4
Log (Na ⁺)	0.8	0.2	0.0	2.3	3.4	0.4	11.4	81.5
Exchangeable Ca ²⁺	4.4	34.0	51.6	8.6	1.1	0.1	0.0	0.0
Log (Exchangeable Mg ²⁺)	4.4	71.1	11.5	8.4	1.3	3.3	0.0	0.0
Silt	18.2	2.1	11.5	68.2	0.0	0.0	0.0	0.0
Clay	63.3	4.6	3.0	29.2	0.0	0.0	0.0	0.0
<i>Mean concentrations</i> (0–15 and 15–30 cm)								
pH	0.3	4.1	3.0	33.5	12.2	46.8	0.0	0.0
Total SOC	72.9	0.2	4.1	0.0	22.1	0.6	0.0	0.0
Total N	58.9	0.8	8.3	0.9	18.9	2.0	8.4	1.8
Log (Na ⁺)	0.2	1.9	8.2	1.5	1.4	8.0	17.9	60.8
Exchangeable Ca ²⁺	57.6	0.0	34.7	7.3	0.0	0.3	0.0	0.0
Log Exchangeable Mg ²⁺	42.9	0.2	22.4	28.4	0.1	5.9	0.0	0.0
Silt	93.1	3.8	2.3	0.7	0.0	0.1	0.0	0.0
Clay	18.4	80.4	1.1	0.1	0.0	0.0	0.0	0.0

[Title Page](#)
[Abstract](#)
[Introduction](#)
[Conclusions](#)
[References](#)
[Tables](#)
[Figures](#)
[⏪](#)
[⏩](#)
[◀](#)
[▶](#)
[Back](#)
[Close](#)
[Full Screen / Esc](#)
[Printer-friendly Version](#)
[Interactive Discussion](#)


SED

7, 1237–1261, 2015

Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

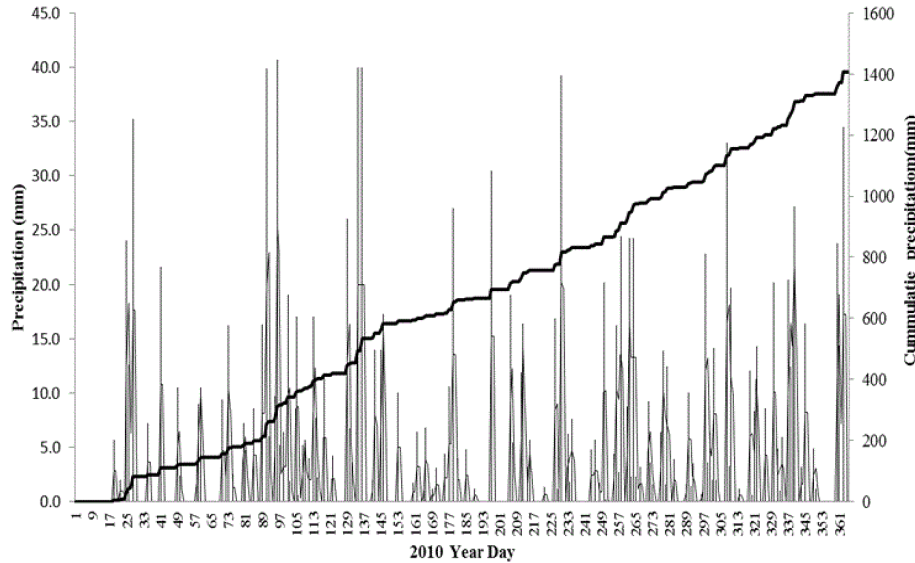


Figure 1. Daily and cumulative precipitation for 2010 for Kiboga district located in one of the climatologically homogenous zones at the Uganda Meteorological Department.

Title Page

Abstract Introduction

Conclusions References

Tables Figures

◀ ▶

◀ ▶

Back Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Precision of simple soil fertility rating approaches in predicting crop yield

P. Musinguzi et al.

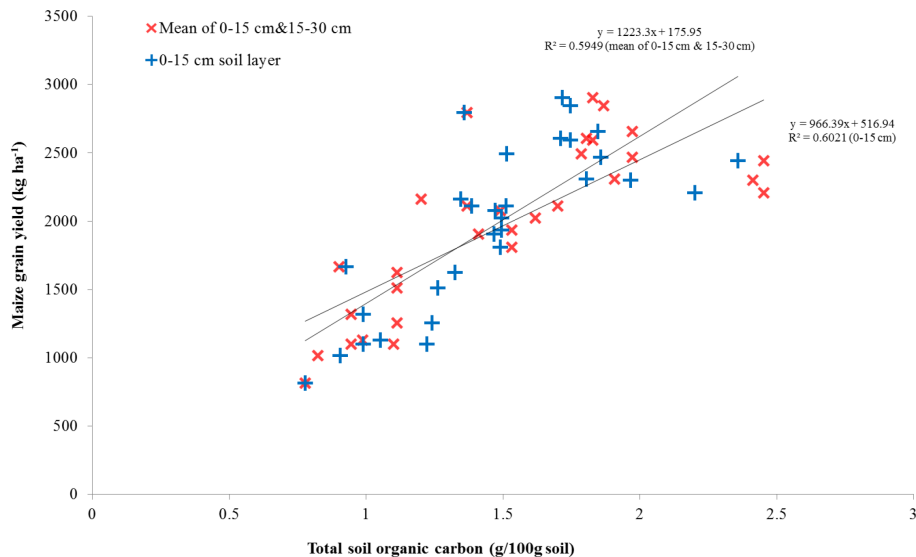


Figure 2. Relationship between maize grain yield and soil organic carbon in a Ferralsol of Uganda.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

