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Using DSSAT-CENTURY Model to Simulate Soil Organic Carbon Dynamics Under a Low-Input Maize Cropping System

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Abstract

Decline in Soil Organic Carbon (SOC) below the critical levels is one of the major indicators of soil fertility depletion in Sub-Saharan Africa (SSA), with the main causes being poor management practices coupled with low input use. Measures for monitoring long-term impacts of management on SOC dynamics and its restoration can be critical in enhancing sustainable soil productivity. Crop models have proved to be good tools for understanding the influence of management options on soil and crop productivity. The DSSAT-Century model was applied to simulate the influence of management practices on SOC dynamics. Using long-term datasets from Kabete, Kenya (1976-1996 maize-bean) and Kiboga-Uganda (1980-2010 maize), model calibration and evaluation showed a good fit between simulated and observed values of SOC. On simulating continuous tillage with no fertilization for the 1980-2010 antecedent period and 2010-2060 extrapolated period, the model showed high rates of SOC decline in the newly cultivated soil as compared to a degraded soil. The simulated rate of decline is 2129 kg ha^{-1} yr^{-1} for newly cultivated soil and 849 kg ha^{-1} yr^{-1} for the continuously cultivated soils. The model was sensitive to initial partitioning of SOC pools, with SOC in previously uncultivated soils declining at a higher rate than that in the cultivated ones. The model confirmed that use of continuous tillage is a major threat to SOC building and soil fertility restoration in the tropics. Adopting conservation agriculture is critical for future generations. Overall, the DSSAT CENTURY model is a potential tool for predicting SOC dynamics in low-input farming systems.

Keywords: simulation, dynamics, long-term, carbon pools, tropical soil

1. Introduction

Soil Organic Carbon (SOC) is a key soil fertility indicator in heterogeneous tropical farming systems in Sub-Saharan Africa (Woomer, Martin, Albretch, Resck, & Scharpenseel, 1994; Musinguzi et al., 2013). Maintenance of high SOC has benefits such as increased cation exchange capacity, moisture storage and mineralizable nutrients; improved soil structure and aggregate stability (Reeves, 1997; Karlen, Andrews, & Doran, 2001). However, SOC varies with soil fertility heterogeneity, resulting in high yield variability, and uncertainty in nutrient management. In the tropics, low fertility soils are associated with low SOC due to poor soil management practices and rapid decomposition (van Keulen, 2001). Restoring SOC to acceptable levels is, therefore, a necessary component of soil fertility improvement and increased crop productivity. Understanding the dynamics of SOC can guide in establishing management approaches for sustainable soil utilisation. In order to understand the processes and practices that affect SOC in terms of its depletion, maintenance and restoration, models that simulate soil and crop performance cannot be underestimated. The DSSAT-CENTURY model was included in the DSSAT v4.0 release in 2004 (Hoogenboom et al., 2004), and is now recommended as an effective tool in modelling low input farming systems in tropical Africa (Gijsman, Hoogenboom, Parton, & Kerridge, 2002). The model simulates SOM decomposition processes as a potential major source of nutrients for some low input farming systems. When the model was compared with a set of other eight soil organic matter models using 12 long-term data sets (Smith et al., 1997), the CENTURY model (Parton, Ojima, Cole, & Schimel, 1994), was among the best. Porter et al. (2010) described major changes to the model by improving initialisation routines to allow flexibility in user input, improving functions for the response of organic matter to changes in soil, water and temperature, and adding a key component of how to mix organic matter components with the soil tillage factor. This makes the model robust enough to simulate low input farming systems. Though explicit use of the model is hampered by limited detailed and long term data sets, simulation is an attractive option to explore management approaches for SOC dynamics, maintenance and restoration. The DSSAT-CENTURY model was thus applied to simulate the effects of management practices on SOC dynamics over years in a maize cropping system in Uganda.

2. Materials and Methods

2.1 An Overview of Carbon Pools in the DSSAT-Century Model

The carbon pool and flow structure of the DSSAT-CENTURY soil organic matter module was revised by Porter et al. (2010). The structure in the model comprises three Soil Organic Matter (SOM) pools, and two pools of fresh residues, both in and on top of the soil. These include:

- The microbial/active material (SOM1).
- The recalcitrant material (SOM2) - derived from cell walls and lignin, decomposed SOM 1 materials, stabilised microbial products such as microbes physically protected by soil structure.
- The largely inert and stable microbial materials (SOM3).
- The metabolic (easy to decompose fresh residuals).
- The structural litter (the recaltrant fresh residuals).

In all, decomposition occurs in the order of days for SOM1, and the two litter components, while years for SOM2, and finally, hundred of years for SOM3. The detailed structure interms of interactions across the diferent carbon pools by the different processes in the soil layers are well decribed by Porter et al. (2010).

Table 1. Soil profile characteristics under cultivated and uncultivated fields in Kiboga district, Uganda

Field type	Latitude: Longtitude	Depth	pH (H_2O)	Total N	SOC	Extractable P (Bray 1)	Extractable K	Ca	Na	Sand	Clay	Silt
		(cm)		%	%	ppm	-----cmol (+)kg^{-1} soil----------			-----------%----------		
Cultivated-Medium fertility (Field 1)	0.80102; 31.92806											
		0-15	5.76	0.18	1.22	0.78	0.19	4.50	0.07	53	35	12
		15-30	5.64	0.07	1.11	0.15	0.08	3.00	0.04	35	53	12
		30-45	5.14	0.06	0.85	0.00	0.07	2.00	0.03	34	55	11
		45-60	4.58	0.06	0.70	0.31	0.07	1.75	0.02	36	54	10
		60-75	4.90	0.05	0.61	0.46	0.06	1.50	0.25	34	56	10
		75-90	4.72	0.07	0.51	0.00	0.06	1.25	0.03	35	55	10
		90-105	4.50	0.05	0.46	0.00	0.07	1.50	0.03	36	57	7
Cultivated-Low fertility (Field 2)	0.86078; 31.89981											
		0-15	4.58	0.11	1.06	2.93	0.15	1.5	0.03	51	38	11
		15-30	4.09	0.08	0.76	0.46	0.07	1.25	0.02	34	47	9
		30-45	4.09	0.05	0.67	0.23	0.07	1.00	0.02	41	48	11
		45-60	4.44	0.40	0.61	0.54	0.07	0.75	0.01	39	51	10
		60-75	4.25	0.07	0.56	0.77	0.06	0.75	0.02	39	52	9
		75-90	4.30	0.017	0.51	0.15	0.06	1.00	0.01	37	52	11
		90-105	4.50	0.025	0.56	0.15	0.07	0.75	0.02	36	53	11
Uncultivated field (field 3)	0.86118; 31.90016											
		0-15	6.80	0.13	2.30	5.18	0.64	2.6	0.06	56	28	16
		15-30	5.00	0.20	2.20	8.94	0.28	5.9	0.09	38	54	8
		30-45	5.40	0.16	1.86	0.92	0.10	2.5	0.04	50	38	12
		45-60	5.00	0.16	1.46	0.31	0.08	1.8	0.07	46	41	13
		60-75	4.90	0.14	1.20	0.15	0.06	1.5	0.07	47	40	13
		75-90	4.90	0.14	1.26	0.07	0.06	1.8	0.02	48	41	11

2.2 Model Calibration Using Seasonal Maize Yield Data

The study was conducted at Lwamata sub-county in Kiboga district (Uganda) in the Central Wooden Savanna agro-ecological zone (Wortmann & Eledu, 1999). The area is characterized by smallholder farming, and the altitude ranges from 1400-1800 m a.s.l. The site experiences mean annual temperature of about 25°C and a bi-modal rainfall pattern (March-June) and (September-October). The dominant soils are Acric Ferralsols typical of a low CEC, pH and <50% base saturation (IUSS Working Group WRB, 2006). The soil climate is isohyperthermic temperature regime, with ustic moisture regime. For the DSSAT model calibration purposes, two soil profile pits were initially dug as a representation of optimum to near optimum soil conditions. An extra soil profile from undisturbed/ uncultivated soil was later included. Soil analyses for all profiles were conducted (Table 1).

A total of 15 fields were used during the long (March-June) and short (September-December) rainy seasons. An open pollinated *Longe 5* maize variety was used as the test crop. Each plot measured 6 m x 5 m. A total of five (5) replicates per fertility class (low, medium and high) were used. Soil fertility of all experimental fields was categorised using a calculated soil fertility index (high parameter values meant high fertility) (Mukashema, 2007). Four core treatments were laid out in a completely randomized design. Major nutrient sources were Urea for N, Muriate of Potash for K and Triple Super Phosphate for P. Four (4) nitrogen fertilizers levels were applied but in a phosphorus and potassium non limiting condition, as per the following treatment combinations; 0N+25P+60K; 25N+25P+60K; 50N+25P+60K; 100N+25P+60K, all in kg ha^{-1}. The same nitrogen rates were applied on different field types but for proper model calibration, optimum soil fertility fields and observed yield were considered. All crop phenological data was also obtained at different growth stages (Tables 2 and 3).

Urea and muriate of potash fertilizers were split applied, with 50% before planting and 50% applied 4 weeks after planting. Phosphorus fertilizer was applied just before planting. The fertilizers were surface broadcast, and later incorporated into the soil with a hoe to a depth of approximately 10 cm. Seeds were planted at a recommended maize spacing of 75 cm inter row and 25 cm intra row, making a population of about 5.33 plants m^{-2}. Weeding was done twice during the season using hand hoes. No pest control measures were employed. Crop phenological data was obtained at different growth stages (Tables 2 and 3). Harvesting was done at physiological maturity by cutting plants at ground level from the four inner rows, and biomass (stover + grain) was measured. The ears and stovers were later separated and sun dried for about 15 days. The ears were hand-shaved to obtain the kernels (grain), which were later weighed. Grains and stovers were further sub-sampled, and later oven-dried at 70°C.

Observed climate data including daily rainfall (mm), daily minimum and maximum temperature (°C) were recorded at the field station (Uganda Meteorological Department, 2011). The daily solar radiation (MJ/m^2/day) data were obtained from NASA Power, as satellite and modelled derived solar data.

Table 2. Crop phenological parameters for *Longe 5* calibration in a medium fertility soil

Season		N rates (kg ha^{-1})	Stover weight (t ha^{-1})	Grain weight (t ha^{-1})	TOP weight (t ha^{-1})	Planting date (dd/mm)/(Julian day)	Anthesis date (dd/mm)/(Julian Day)	Physiological maturity Date (dd/mm)/(Julian day)	Harvest Date (dd/mm)
2010A	1	0	3.65	1.07	4.72	18/03 (77)	17/05 (122)	10/07 (175)	17/07
(Mar-June)	2	25	4.45	2.56	7.01	18/03 (77)	17/05 (122)	10/07 (175)	17/07
	3	50	5.75	3.1	8.85	18/03 (77)	17/05 (122)	10/07 (175)	17/07
	4	100	5.49	3.21	8.7	18/03 (77)	17/05 (122)	10/07 (175)	17/07
2010B	1	0	3.75	1.05	4.8	02/09 (243)	2/11 (305)	25/12 (359)	8/01(2011)
(Sep-Dec)	2	25	4.11	3.06	7.17	02/09 (243)	2/11 (305)	25/12 (359)	8/01(2011)
	3	50	4.17	3.17	6.34	02/09 (243)	2/11 (305)	25/12 (359)	8/01(2011)
	4	100	5.87	3.95	9.52	02/09 (243)	2/11 (305)	25/12 (359)	8/01(2011)

Table 3. Crop phenological parameters for *longe 5* validation in a low fertility soil

Season		N rates (kg ha^{-1})	Stover weight (t ha^{-1})	Grain weight (t ha^{-1})	TOP weight (t ha^{-1})	Planting date (dd/mm)/(Julian day)	Anthesis date (dd/mm)/(Julian Day)	Physiological maturity Date (dd/mm)/(Julian day)	Harvest Date (dd/mm)
2010A (Mar-June)	1	0	2.75	1.01	3.76	18/03 (77)	17/05 (122)	10/07 (175)	17/07
	2	25	3.55	2.06	5.61	18/03 (77)	17/05 (122)	10/07 (175)	17/07
	3	50	3.85	2.9	6.75	18/03 (77)	17/05 (122)	10/07 (175)	17/07
	4	100	4.29	3.31	7.6	18/03 (77)	17/05 (122)	10/07 (175)	17/07
2010B	1	0	2.65	1.25	3.9	02/09 (243)	2/11 (305)	25/12 (359)	8/01(2011)
(Sept-Dec)	2	25	3.21	2.16	5.37	02/09 (243)	2/11 (305)	25/12 (359)	8/01(2011)
	3	50	4.27	3.27	7.54	02/09 (243)	2/11 (305)	25/12 (359)	8/01(2011)
	4	100	4.17	3.65	7.82	02/09 (243)	2/11 (305)	25/12 (359)	8/01(2011)

Using collected phenological data from the field experiment (Tables 2 and 3), a model calibration for *Longe 5* maize variety was conducted. DSSAT genetic coefficient parameters were adjusted using a medium season default variety in DSSAT as a basis. The calibrated cultivar parameters are P1=285.0, P2=0.500, P3=730.0, G2=620.0, G3=8.19 and PHINT=38.00. The calibration was carried out on the variety to improve model outputs by adjusting these coefficients to obtain a low RMSE and a high d-statistic. The model was validated using another maize dataset from Kaizzi et al. (2012) conducted in Hoima district, Western Uganda.

Soil moisture was estimated as 70% of field capacity at the beginning of rains based on experience with these soils and conditions. Soil parameters that were not measured in the field were estimated using available pedotransfer functions (Gijsman, Hoogenboom, Parton, & Kerridge, 2002). The Lower Limit (LL) and Drainage Upper Limit (DUL) were derived according to the Nearest Neighbor method (Jagtap, Lal, Jones, Gijsman, & Ritchie, 2004). Soil bulky density was estimated according to Gijsman, Hoogenboom, Parton, and Kerridge (2002). Given the nature of the soil, the run-off curve number of 63 was used in relation to its runoff potential (Chow, Maidment, & Mays, 1988).

Table 4. Carbon and Nitrogen distribution in physically fractionated particles from the low fertility, medium fertility and uncultivated soil profiles in the upper 0-15 cm soil layer

C & N in particle sized Fractions	Field 1 (medium fertility)	Field 2 (Low fertility)	Field 3 (uncultivated soil)	Carbon in each fraction (%) of variable fertility fields		
	--------------g kg^{-1} soil---------------			Medium	Low	Shrub-land
C-Sand (SOM 1)	1.54	0.86	2.92	16.80	11.20	22.90
C-Silt (SOM 2)	1.59	1.51	3.07	17.40	19.58	24.00
C-Clay (SOM3)	6.02	5.34	6.76	65.80	69.26	53.01
N-Sand	0.07	0.05	0.09			
N-Silt	0.16	0.15	0.29			
N-Clay	0.59	0.32	0.67			

Note: The sand –sized fraction represents **SOM1** in CENTURY model (microbial or active material), **SOM2** is represented by the silt-sized fraction which is the recalcitrant material (derived from lignin, cell walls) or decomposed SOM1 and stabilized microbial materials (microbes that are physically protected by the soil); while **SOM3** is represented by the clay-sized fraction (the largely inert material and stabilized microbial material) (Feller & Beare, 1997; Christensen, 1992).

2.3 Model Calibration and Validation Using Long-Term Data

In order to evaluate the DSSAT-CENTURY model in simulating soil organic matter dynamics over a long period of time, different datasets were used for calibration, and validation.

2.3.1 Long-Term Soil Fertility Data Set for Model Calibration

The crop rotation or sequence tool as availed in the DSSAT V4.5 was used to simulate long-term maize-based production systems. The tools enabled simulation and analysis of responses of crop and soil processes (Bowen, Thornton, & Hoogenboom, 1998). Climate, soils and crop data were obtained from a long term experiment carried out at Kabete site at the Kenya Agricultural Research Institute (1976–2001), located in a semi-humid region (Kamoni et al., 2007). Soils are predominantly humic Nitisols (FAO/UNESCO, 1990) or Alfisols (USDA, 1975), with clay texture (locally as Kikuyu Red clay Loam). Most data on soils were obtained from Qureshi (1991). The area has a mean annual precipitation of 981 mm, which falls in two rainy seasons; March to May (the long rains) and mid October to December (the short rains) (KMD, 2012). Mean annual temperature ranges from 18 to 21°C. All climate data were obtained from the weather stations at the institute as provided by the Kenya Meteorological Department. Though a total of 18 treatments were applied in the experiment, for this calibration, we considered plots with no input applications (controls). A hybrid 514 maize variety (exists in DSSAT) was considered in rotation with local bean (*Mwezi moja-Rose coco* variety). The model was set with planting dates within the first weeks of the planting seasons, at a spacing of 75 cm X 50 cm for maize. Long term total SOC (t ha^{-1}) was compared with simulated total SOC. Initial SOC values measured before the start of the research in 1976 ranged from 33 to 36 t C ha^{-1}, with an average of 34 t C ha^{-1} but increasing slightly to 35 t ha^{-1} in 1980, then decreasing to 27 t C ha^{-1} by 1996. This was represented in the model as represented 1.62-1.73 % SOC, 1.68% SOC and 1.29% SOC for 1976, 1980 and 1996 respectively. Total soil organic carbon (kg ha^{-1}) in profile was estimated to be equal to the levels of SOC distribution across the four soil layers at a bulky density of 1380 kg m^{-3} to a soil depth of 120 cm.

2.3.2 Model Validation by Comparing Cultivated and Previously Uncultivated Reference Soils

Two seasons maize experiment datasets for *Longe 5* from Kiboga district were used, on land that had continuously been cultivated. Datasets from cultivated and previously uncultivated soil profiles pits (Table 1) were used as inputs to the model. The cultivated soil is represented by SOC levels in 2010 in the medium fertility field (depicting depletion over 30 years of maize cultivation). The previously uncultivated soil in the shrub-land (Table 1), identified within the same location, represented SOC status in 1980 before clearing the land. Such land is believed to have attained steady state. Model sensitivity to low SOC and inputs was conducted before use of the model for long-term simulation.

All measured carbon associated with particle-sized fractions were obtained after physical fractionation. Carbon associated with sand-sized particles were considered SOM1, while silt- and clay-sized heavy fractions were considered as less labile (SOM2) and stable/inert fractions (SOM3), respectively (Feller & Beare, 1997; Christensen, 1992) (Table 2). Carbon and nitrogen analytical results were applied to estimate C/N for SOM1, SOM2, and SOM3 (Table 4).

2.3.3 Model Considerations to Simulate Soil Organic Carbon Dynamics and Restoration

The cropping sequence DSSAT model application was applied to simulate SOC and maize yields trends for the next 50 years, and the simulation demonstrated clear patterns of change in SOC over years. The time-series analysis in the sequence type of experiment was considered. The effect of management on the restoration of soil organic carbon was assessed in a sole maize-based farming system. Notably, in SOC simulation, the carbon released by decomposition is partly lost through CO_2 respiration, and the remaining carbon is transferred to more stable organic matter pools. The decomposition rate of all SOM fractions is usually a function of temperature, moisture, cultivation and texture (Parton, Ojima, Cole, & Schimel, 1994). With most tropical soils characterised by high SOM decomposition (van Keulen, 2001), three major practices that would regulate the decomposition processes were included in modelling, that is, zero tillage, soil surface cover (percent residual retention), combined use of cattle manure and NPK fertilizers. These management scenarios were evaluated under a simulated continuous maize rotation for 30 years. The model was set using the initial soil conditions of stable SOC presented in Table 4. For uncultivated soil (shrubland), default model values of 44% stable carbon were applied while for cultivated soil with depleted fertility, 34% stable C was used.

An analysis of SOC dynamics in a tropical soil under different management practices was conducted under a low input system. Both SOM 1 and SOM2 were considered in simulating SOC dynamics in soils within a 30 year period (1980-2010) and prediction of SOC status in the next 50 years on assumption that the same climatic conditions are maintained. In the simulation, current dominant practices such as continuous tillage and zero mineral fertilizer were compared with the impact of no tillage, retaining surface residual after harvest, and organic manure applications. These comparisons were simulated on three soils of variable fertility with low, medium and high initial stable SOC levels **(**Table 4). Simulations were conducted of SOC status after 50 years of cultivation under a cultivated and previously cultivated soil was conducted.

2.4 Statistical Analysis

Statistical model evaluation was conducted using correlation coefficient, mean ratio and mean difference (RMSE). Correlation coefficient (r) is a measure of the degree of association between simulated and measured data. The target was to have a low RMSE and high r value. The *RMSE* was calculated as:

$$\text{RMSE}=\frac{1}{\text{n}\sum_{i=1}^{n}(Si-Oi).^{2}).^{0.5}} \tag{i}$$

where S_i and O_i are a corresponding pair of simulated and measured values, respectively, and n is the number of observations included in the evaluation.

3. Results and Discussion

3.1 Model Calibration and Validation for Longe 5 Open Pollinated Maize Variety

The DSSAT-CERES Maize model was calibrated and evaluated using fields 1 and 2, and it resulted in relatively good and robust simulated biomass, grain yields and dates of anthesis and physiological maturity. The RMSE for the grain yield and above ground biomass was 1250.38 and 986.51 respectively, with simulated: measured yield ratio ranging from 0.8-1.3 (Table 5). The model was also sensitive to nitrogen fertilizer additions, with highest yield responses simulated with 50 and 100 kg N. Simulated responses of yields were not significant for the poor and medium fertility fields. The performance of the model was robust in simulating maize yields in our low input systems. With *Longe 5* variety, an open pollinated variety, the simulated yield ranges fall within the average observed yields that have been reported in Uganda.

Table 5. Model outputs of simulated and observed selected maize parameters

Season	N rates (kg ha^{-1})	Grain Yield (kg ha^{-1})			Biomass (kg ha^{-1})			Anthesis Date		Physiological maturity date	
		Simulated	Observed	Mean ratio	Simulated	Observed	Mean ratio	Simulated	Observed	Simulated	Observed
Field 1 (Medium fertility)											
2010A	1 0	1221	1070	0.9	3672	4720	1.3	63	62	116	115
	2 25	2060	2560	1.2	6771	7010	1.0	63	62	116	115
	3 50	3447	3100	0.9	7831	8850	1.1	63	62	116	115
	4 100	3122	3210	1.0	8766	8700	1.0	63	62	116	115
2010B	1 0	1486	1050	0.7	4247	4800	1.1	63	62	116	116
	2 25	2552	3060	1.2	6436	7170	1.1	63	62	116	115
	3 50	2917	3170	1.1	7253	8340	1.1	63	62	116	115
	4 100	3248	3950	1.2	6708	9220	1.4	63	62	116	115
Field 2 (Low fertility)											
2010A	1 0	1324	1010	0.8	3257	3760	1.2	63	62	116	115
	2 25	2748	2060	0.7	6006	5610	0.9	63	62	116	115
	3 50	3598	2900	0.8	7502	6750	0.9	63	62	116	115
	4 100	3613	3310	0.9	7674	7600	1.0	63	62	116	115
2010B	1 0	1600	1250	0.8	4522	3900	0.9	62	61	116	115
	2 25	2696	2160	0.8	6669	5370	0.8	62	61	116	115
	3 50	3151	3270	1.0	7570	7540	1.0	62	61	116	115
	4 100	3161	3650	1.2	7605	7820	1.0	62	61	116	115

3.2 Model Calibration and Validation for Simulating Long-Term SOC Dynamics in a Tropical Soil

For Kabete-Kenya long-term trials and Kiboga-Uganda maize trials, the DSSAT Century model resulted in a positive fit between the simulated and measured SOC values (Figure 1 and 2). Only the Kabete-Kenya datasets indicated a poor correlation during the mid years with high observed SOC levels.

On conducting a simulation for different soil fertility gradients with varying initial soil carbon and initial fraction of stable organic matter under maize cropping system in Kiboga-Uganda soils over a 1980-2010 period, high rates of SOC decline were notable in previously uncultivated soils as compared to cultivated soil with low soil fertility (Figures 3 and 4). The sharp decline in organic matter in the newly cultivated land showed that the active pool (SOM1) and intermediate (SOM 2) dominated the shrub-land, and when subjected to harsh conditions in tropical climate, there is rapid increase in the rate of decomposition and carbon loss. High initial organic carbon in uncultivated soil composed of probably high decomposable matter that tends to be highly sensitive to tropical climatic conditions. The cultivated and low fertility soils showed much resilience to decomposition. Such soils are dominated by passive and inert C fractions, which are not easily decomposable (Olk & Gregorich, 2006). The model was, therefore, sensitive to these initial soil organic carbon settings in the two different locations.

However, the CENTURY SOM model did not show strong responses to changes in tillage practices or use of organic manure in an effort to restore SOC (simulated results not shown). Similar model results were reported in model sensitivity analyses with fewer changes in SOC on tillage, fertilization and irrigation (Porter et al., 2010). This simulation results need to be validated with long-term measured data on tillage in order to reach acceptable conclusions. Nevertheless, simulated responses to added organic inputs or change of tillage practices may also require changes in the current parameter setting in the SOM residual model. The current default settings rates of 0.02, 0.00054, and 0.000012 d^{-1}, for SOM1, SOM2, and SOM3 respectively (Gijsman, Hoogenboom, Parton, & Kerridge, 2002), need to be revised based on measured field data. Other model parameters like the decomposition rates for each of the organic matter pools need to be validated in model parameterization using observed data sets (Parton et al., 1994).

Since most studies have demonstrated that the largely inert pools (SOM3) may take more than 100 years for decomposition to occur (von Lutzow et al., 2008), management of SOM1 and SOM2 in the tropics is a good option. Consideration of on-farm variability in the context of the differences in the quality of organic materials in terms of lignin + polyphenols content (Palm, Gachengo, Delve, Cadisch, & Giller, 2001) would also guide in model validation processes. Evaluating the C:N ratios for structural and metabolic pools for organic materials for most tropical organic materials entering the SOM pools would also control the rate of immobilization and mineralization, and possibly improve on model parameterization. The simulated dynamics of SOC in the previously uncultivated soil is a clear demonstration of model capacity to simulate the role of microbes commonly active under SOM1 and SOM2. Therefore, changes of soil fertility using SOC as indicator can be simulated excellently given the differences in the initial % distribution of the inert C fraction.

In the extrapolated simulations for the next 50 years, most of the decline in SOC was associated with undisturbed soils with high proportions of labile C (Figure 4). Total SOC projections show a decline from 233 t ha^{-1} to 130 t ha^{-1} by 2060 for soil currently opened up (previously uncultivated) for maize production, while degraded/cultivated fields are predicted to reduce from 124 t ha^{-1} to 81.4 t ha^{-1} (Figure 4). The simulated rate of decline is estimated at 2129 kg ha^{-1} yr^{-1} for newly cultivated soil and 849 kg ha^{-1} yr^{-1} for the continuously cultivated soils. Exponential equations were also fit to predict SOC dynamics over years, with clear differences in rate of change of SOC. Simulation of yields also showed a significant decline over the next 50 years (Figure 5) except that there was evidence of high yield variability over the years. This level of variability is a common challenge in tropical soils, and remains a challenge for agriculture in Uganda. Measures that can enhance use of the DSSAT model in soil management under heterogeneous farming systems are critical. Changing from conventional tillage and related poor soil management to embarking on soil organic carbon building is very important for tropical soils. Rapid changes in SOC and consequently soil fertility suggest the need to begin planning earlier for low-input systems since climate change is another potential threat.

The good congruence in the observed and simulated is a clear suggestion that the model is a potential tool that can be used to guide impact of management effects on SOC dynamics in low input systems. The simulations suggest that tropical soils have high SOC depletion, and restoring such levels and maintaining the soil to acceptable SOC content is needed for improved yield and agronomic efficiencies to added fertilizers in maize production. With most farmers opening up land for agricultural use, it is critical that soils are given priority by adopting soil conservation practices such as conservation tillage, encouraging retention of crop residues, applying manure and mineral fertilizers. The current paradigm shift for obtaining high crop yield by adopting integrated soil fertility management in SSA (Vanlanuwe et al., 2010; Musinguzi et al., 2013) need to be emphasized as a means for increasing SOC content.

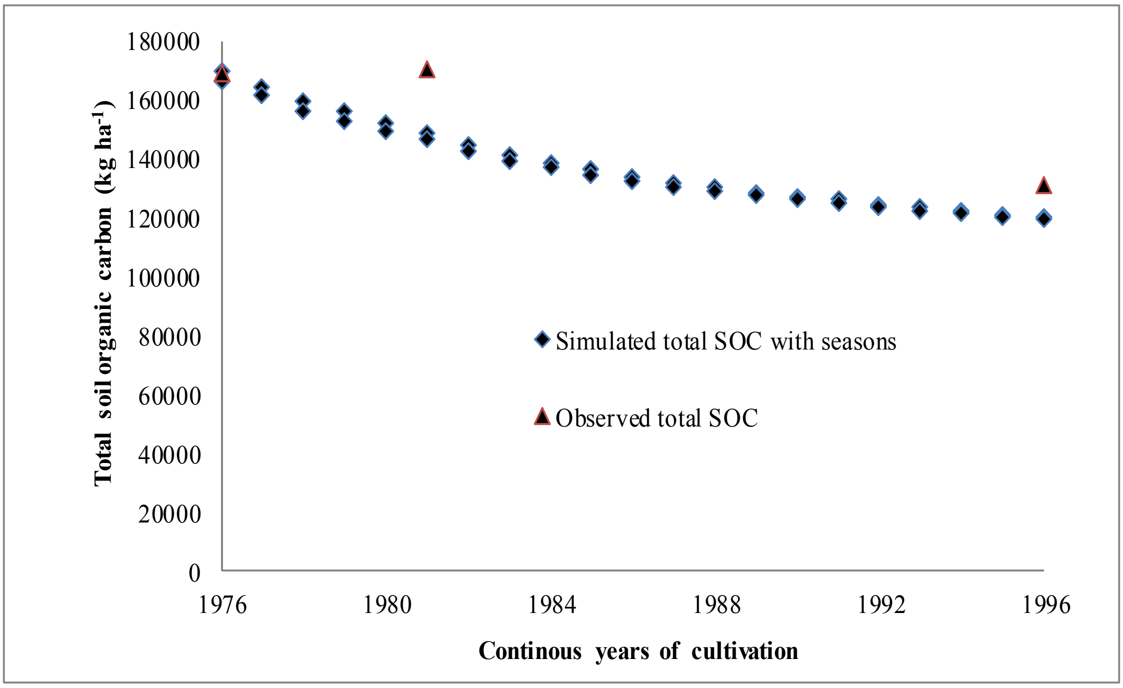

Figure 1. DSSAT-CENTURY simulated and measured total soil organic carbon changes on a long term maize-bean cropping system (without input application) in Kabete, Kenya

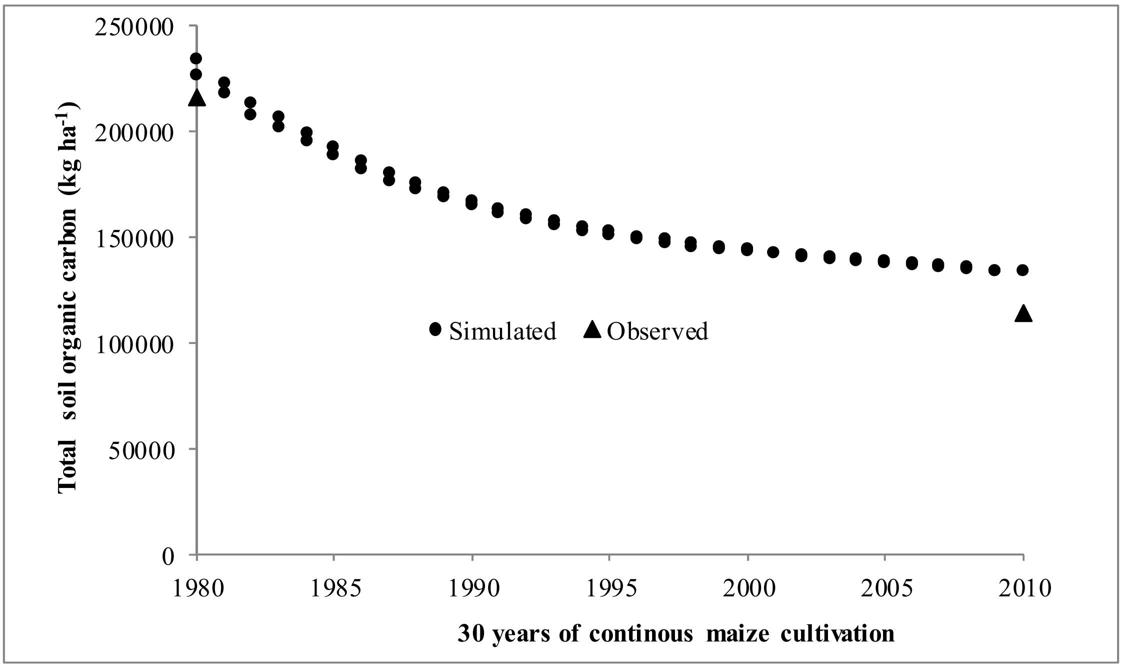

Figure 2. DSSAT-CENTURY simulated and measured total soil organic carbon changes on a shrub land (representing previously uncultivated land in 1980) cultivated continuously for 30 years in Kiboga district, central Uganda

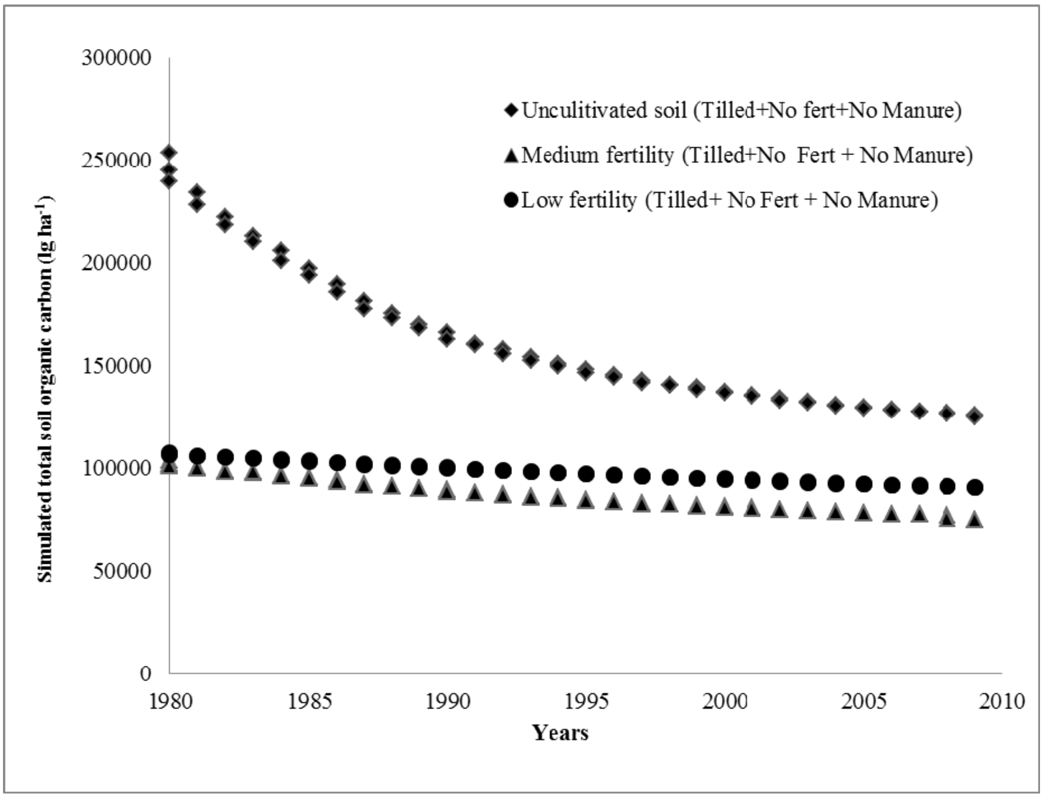

Figure 3. DSSAT-CENTURY simulations of total soil organic carbon dynamics under variable soil fertility fields in maize production

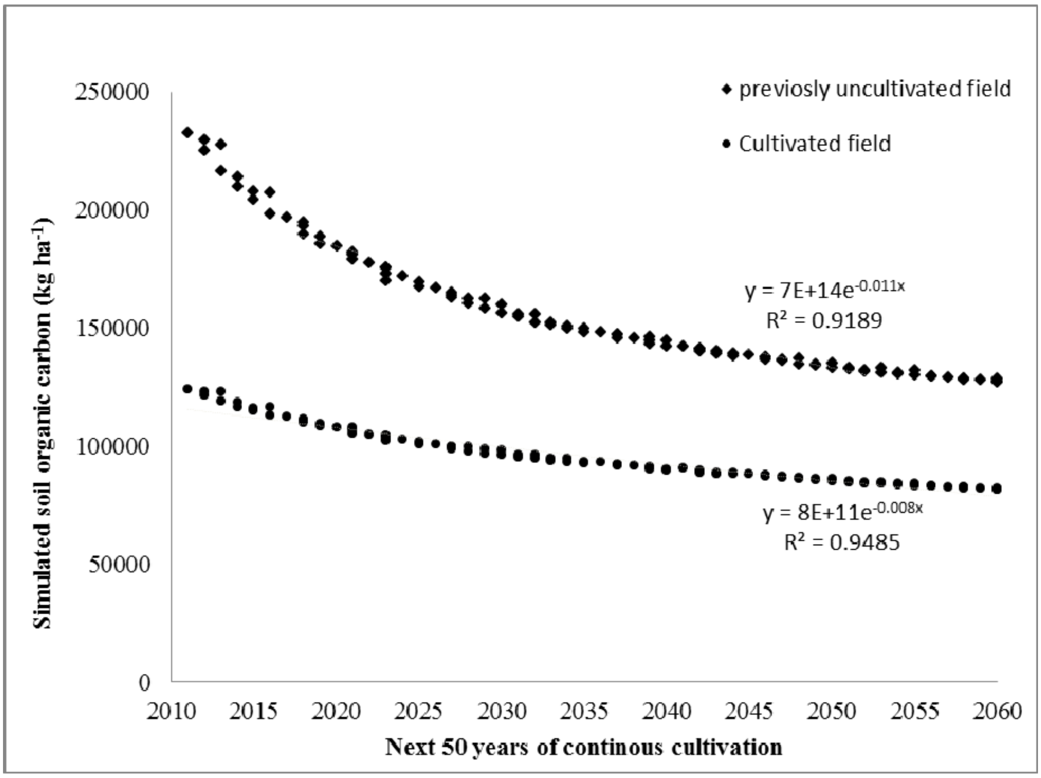

Figure 4. DSSAT-Century simulations of changes in soil organic carbon for a newly opened land and depleted soil under continuous maize cultivation in a tropical Ferralsol

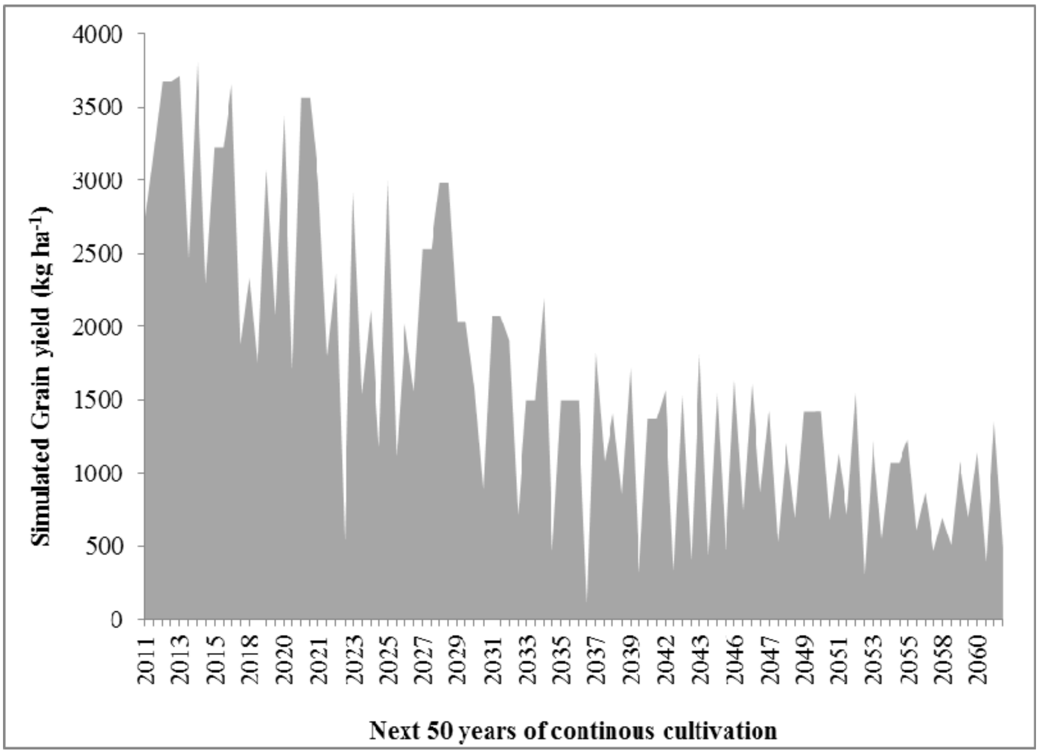

Figure 5. DSSAT-Century simulations of grain yields for a cultivated soil under maize on a tropical Ferralsol

4. Conclusion

The DSSAT-CENTURY model demonstrated its excellent capacity to simulate long-term SOC dynamics in a low-input maize-based system. Model sensitivity to initial soil organic carbon and its pools is a clear illustration of the flexibility of the model for simulating complex heterogeneous farming systems in the tropics. Since most farmers in SSA rely on SOM as a major source of nutrients, the model could be useful to guide in identifying appropriate management options for soil fertility restoration. Long-term experiments in tropical Africa are also critical in improving the understanding of concomitant effects of added organic inputs or conservation agricultural practices to SOC restoration.

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