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## Accumulation of SOC under organic and no-fertilizations, and its influence on crop yields in Tanzania's semiarid zone

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### ABSTRACT

**Introduction:** To estimate differential accumulation of soil organic carbon (SOC) and its ecological significance is very important to smallholder farmers in the Tanzania's semiarid areas. This study investigated the accumulation of SOC and other important soil nutrients under organic and no-fertilizations, and correlated SOC with crop yields. Using data from long-term experimental study sites of semiarid in Tanzania, we estimated SOC accumulation in different soil treatments and depths where a total of 128 soil samples were collected at the depths of 0–20 cm and 20–40 cm from two villages (sites) with organic fertilization and no-fertilization treatments. Sites under organic fertilization were defined as those which have received manure fertilization for more than 5 years on continuum basis.

**Outcomes:** The accumulation of SOC was significantly greater in soils under organic fertilizations (1.15 and 0.80 MgC ha<sup>-1</sup> at soil depth and 20–40 cm) and decreased with increasing soil depths. Similarly, TN and P decreased from 0.40 and 2.40 Mg (0–20 cm) to 0.16 and 2.10 Mg (20–40 cm), respectively. Other important soil nutrients such as calcium (Ca<sup>2+</sup>), potassium (K<sup>+</sup>), magnesium (Mg<sup>2+</sup>), and sodium (Na<sup>+</sup>) had similar pattern. In addition, soil bulk density was less under organic fertilization (1.1 g/cm<sup>3</sup>) than under no-fertilization (1.2 g/cm<sup>3</sup>) and it increased with soil depths. Correspondingly, the crop yields were significantly higher (1.6 tn ha<sup>-1</sup>) under organic fertilizations than (0.6 tn ha<sup>-1</sup>) under no-fertilizations indicating that crop yields were significantly affected by SOC.

**Discussion:** Organic fertilization i.e., especially cattle manure in the area has considerable fertility potential. To optimize soil fertility potential, we need to consider such kind of fertilization from household to national level.

**Conclusion:** Our results demonstrated that manure application was the best fertilization method for improving soil fertility in most croplands of Tanzania's semiarid areas, especially in this era of climate change scenarios.

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Agriculture; ecosystems; environment; farm management; semiarid; Tanzania

### Introduction

The present study aims to address the problem of low soil fertility in semiarid areas (Novara et al. 2017; Keesstra et al. 2018). This crisis is attributed by long-term monoculture system with insufficient or lack of soil fertilizations (Parras-Alcántara et al. 2016; Rodrigo-Comino et al. 2016; Galati et al. 2016). In this aspect, there is a need to undertake soil fertilization (i.e., especially organic soil amendments) to optimize various soil nutrients. This kind of amendment is environmentally friendly and economically viable (Parras-Alcántara et al. 2016). In doing so, it focuses on the accumulation of soil organic carbon (SOC) and its influence to crop yields in semiarid agroecosystem (Rossi 2009; Usuga et al. 2010; Batjes 2011; Araujo, Zinn, and Lal 2017). The accumulation under study is mainly attributed by soil organic management, i.e., organic fertilization (Batjes 1992; Sombroek, Nachtergaele, and Hebel 1993; Novara et al. 2016a). Lal

(2008) clarified that despite climates and vegetation having significant contribution to SOC accumulation at global level, soil organic management is prominent in doing so at farm level. Besides, soil depth has significant influence on SOC accumulation in various agroecology (Wang et al. 2010). However, the results from quantum calculation of SOC may have spatial and temporal variation (Novara et al. 2016b; Johannes et al. 2017; Cerdà et al. 2017; Sollinsa and Gregg 2017).

The amount of carbon stored in soil is determined by the balance of two biotic processes namely; production of organic matter (OM) by terrestrial vegetation and its decomposition by soil organisms (IPCC 2000a; Roose and Barthes 2001; Lal 2004; Vanlauwe, Wendt, and Giller 2014). Soil organic matter (SOM) mainly comes from the remains of plants and animals, and is constituted by many organic chemical components (carbohydrates, lipids, proteins) which are carbon sources for the microbial activity of the soil. Thus, it is certain that SOC

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increases through the decomposition of SOM (Mol and Keesstra 2012; Keesstra et al. 2016). Significantly, Batjes (1996) realized that accumulation SOC is a key component of any terrestrial ecosystem, and any variation in its abundance and composition has important effects on many of the processes (i.e., agriculture) that occur within the system.

Tanzania has limited studies that explore the accumulation of SOC under different soil managements (Kaaya et al. 2013; Shelukindo et al. 2014; Vanlauwe, Wendt, and Giller 2014). Some of these studies have examined fertility and OM stability of savanna soils, permanent acacia cropping, accumulation of SOC under permanent sisal cropping, and the effects of manure in homestead fields on organic C and N mineralization (Hartemink 1997; Glaser et al. 2001; Hartemink, Veldkamp, and Bai 2008). Other studies have estimated SOC under natural ecosystems such as forestry and pasture but with very limited information on cropland (Munishi and Shear 2004; Elberling et al. 2007; Rossi et al. 2009; Mäkipää et al. 2012; Kaaya et al. 2013). Thus, very little has been done in explaining the same on semiarid agroecosystem, i.e., among the most vulnerable ecosystems in Tanzania.

Many semiarid soils of Tanzania have poor nutrients especially when the farming systems are not well conducted (Palm et al. 2001; Roose and Barthes 2001; Vanlauwe 2004; Wang et al. 2010). Thus, to optimize soil nutrients in these areas, there is a need to adopt good agriculture practice (Kimaro et al. 2015). Among others, soil organic management can have a good attribute on this aspect (IPCC 2003; UNFCCC 2007; Baddeley, Edwards, and Watson 2017). Various scholars have established that the soils under organic management is rich in OM with moderate permeability (Glaser et al. 2001; Lal 2004; Solomon, Lehmann, and Zech 2000). Apart from animal dung, soil organic management comprises the decomposition of plant biomass and animal residuals (Christensen 1988; Duan et al. 2011).

In most cases, the existing complexity that happens during the interaction among chemical, biological, and physical processes necessitates proper soil organic management to achieve optimal soil fertility (Glaser et al. 2001; Lal 2008; Araujo, Zinn, and Lal 2017). This is because a wide range of soil nutrients, i.e., carbon, nitrogen, phosphorus, and preferable pH are attainable under soil organic management (Kimaro et al. 2015; Baddeley, Edwards, and Watson 2017). These nutrients increase the yields of various crops such as maize, sorghum, and millet. Ecologically, organic fertilizations boost the interaction between soil microbes and plant roots to facilitate nutrients uptake which eventually optimize yields (Bationo et al. 2006).

Specifically, SOC plays a significant role in supplying plant nutrients and enhancing cation exchange

capacity (Rossi 2009; Usuga et al. 2010; Batjes 2011; Smith et al. 2011; Araujo, Zinn, and Lal 2017; Bokhorst et al. 2017; Qin et al. 2017).

Although the science of assessing the changes in the soil's fertility in various agroecological zones is progressing rapidly (Mishra et al. 2017), a variety of knowledge gaps still exist. This is about the actual assessment of SOC accumulation under different soil treatment and its influence to crop yields in most semiarid agroecological zones. As results, the soil amendments will elicit crop yields to raise food security and socioeconomic development in semiarid areas of Tanzania (where most people are poor). The yields' optimization can be achieved by increasing soil fertility through organic fertilization. This approach is the most accurate and simplest way of increasing soil fertility as per the life standards of the majority people in the area. In doing so, we will have determined the exact potentials of organic fertilization in optimizing SOC accumulation for soil fertility, increasing yields, and providing energy for soil microbes.

Further, it will bring significant contribution to farmers in the area and other marginalized rural communities in the mechanisms of coping, adaptation, and mitigation to global climate change (Johannes et al. 2017). Consequently, despite the fact that the relation between an increase in OM input and its effects on the SOM and yields has been established in most developed countries, it is quite understandable that the present study will have established this knowledge in a developing country where this knowledge is quite limited. Knowledge about the impact of organic fertilizations on soil fertility improvement is not only important for general understanding the ecology of semiarid, but also for in-depth evaluation of the potentials and constraints of agricultural production in this vulnerable agroecosystem.

Therefore, the current study aims at: (1) Quantifying SOC accumulation and other important soil nutrients under organic and no-fertilizations at different soil depths; (2) Evaluating the relationship between SOC under organic and no-fertilizations; (3) Establishing the correlations between SOC and crop yields, and proposing its utility for agro-social issues. We selected SOC because it adequately supplies energy to mycorrhizae fungi that in turn helps the process of nutrient uptake for crop growth and production (Smith et al. 2011). Thus far, to achieve these objectives, soil management was mainly hypothesized and tested against the SOC accumulation and yields.

## Materials and methods

### Site description

The study site is located at the villages of Mnyakongo and Ugogoni (6°12'8.47"S, 30°23'25.25"E and 6°15'

6.59°S, 30°27'8.78"E), respectively, with 900–910 m above sea level (a.s.l.), Kongwa District, Dodoma Region, Tanzania. The site is located in one of the most sensitive zones to climate variability and change. Field experiment was conducted June and September, 2016 in the villages (sites), i.e., Mnyakongo and Ugogoni (GPS (6.2 36.41667)). The detail on the design and sampling procedures is described in the soil sampling section. The District has an area of about 4041 km<sup>2</sup> with an elevation ranging 900–1000 m a.s.l. and is located on the leeward side of Ukaguru Mountains. The annual precipitation varies with elevation and ranges from 400 mm at 900 m a.s.l. to 800 mm at 1000 m a.s.l. The dominant soils are fluvisols and vertisols (United States Department of Agriculture soil taxonomic system) as seen in Table 1.

According to Food and Agricultural Organisation and The United Nations Educational, Scientific and Cultural Organisation (FAO-UNESCO 1988), Kongwa District is categorized into three major physiographic units, namely: (1) mountains, (2) uplands, (3) lowlands (Table 1). In this article, data are presented from the lowlands which cover about 74% of the district. The seasonal rainfall pattern in Kongwa District is greatly influenced by the eastern-western wind that blows from the Coast and Morogoro regions. The rain pattern is unimodal with the mean annual precipitation of 400–600 mm and the maximum of rain occurs between December and March. The rainfall at the research site averages between 500 and 600 mm per annum. The potential evaporation (Penman) is about 500–700 mm yr<sup>-1</sup> and thus exceeding the total amount of rainfall except in January and March. There is a considerable variation in rainfall pattern between years, and throughout the district, rainfall is highly unpredictable. Mean annual temperature is 26°C with only minor fluctuations.

According to FAO (1988), the soil units in the area includes: *Leptosols*, *Luvisols*, *Phaeozems*, *Cambisols*, *Arenosols*, *Fluvisols*, *Vertisols*, *Gleysols*, and *Solonchaks* with a sandy loam texture as seen in Table 1. The silt concentration of the soil at the different farms were not significantly different ( $p > 0.05$ ) and ranged between 170 and 255 g kg<sup>-1</sup> soil with a bulk density ( $\rho_d$ ) between 1.21 and 1.63 Mg m<sup>-3</sup>. The soils are neutral to alkaline pH value, medium level of organic C, N, P, K, and other trace soil elements. It has moderately high cation exchange capacity and high base saturation

(Solomon, Lehmann, and Zech 2000; Glaser et al. 2001; Bationo et al. 2006). The vegetation type of the Central Tanzania is of bush or thicket.

The farms were mostly tilled with hand hoe, i.e., small holders farming. The main difference among the treatments was that the farms that received animal manure for about 5 years consecutively were regarded as under organic fertilization, whereas those that didn't receive manure or other chemical fertilizers for that couple of time were regarded as under no fertilizations. This was also evidently observed in the field. Consequently, farms were purposely selected based on such treatments. To determine the time of soil treatment, a 5-year (2010–2015) time frame was established. In all treatments; maize, sorghum, and millet were mainly intercropped. In these farms, there were no chemical fertilizations. In-depth information is stipulated in the sampling section below.

### Farming situation in the area

In the study area, the dominant agricultural farming systems are cropping, livestock, and agro-pastoralism (Elberling et al. 2007). The tillage system is both conventional and conservation (Mkonda and He 2017d). Monoculture has been a dominant system in the area and has resulted to exhaustion of soil quality (Hartemink 1997; Glaser et al. 2001; Hartemink, Veldkamp, and Bai 2008). Such a situation has affected the production systems and, thus, is leading to poor yields and frequent food shortage (Christensen 1988; Duan et al. 2011).

To restore the situation, we need to assess the magnitude of soil fertility deficit under different soils management scenarios. This is because in areas under organic fertilizations, soil nutrients (carbon, nitrogen, phosphorus, and potassium, just to mention a few) are abundant to provide favorable condition for crop production (Johannes et al. 2017). Application of animal dungs (manure) can be a reasonable solution as it increases the fore-mentioned nutrients especially SOC to maintain soil productivity; however, the degree of magnitude depends on the amount applied (Christensen 1988; Duan et al. 2011). Literally, most farmers in the area have an average of 4–6 ha per household that can be easily fertilized by animal dung collected from there (Palm et al. 2001; Vanlauwe 2004; Bationo et al. 2006). According to the District Agricultural and Livestock Development

**Table 1.** Main physiographic units and soils in Kongwa District.

Physiographic units	km <sup>2</sup>	Altitude	Lithology	Dominant Major Soils
Mountains	400	980–2000	Mainly Precambrian gneiss	Luvisols, Phaeozems, Leptosols, Ferralsols
Uplands	641	920–980	Acid and intermediate Metamorphic rocks	Luvisols, Ferralsols, Cambisols, Arenosols
Lowlands	3000	900–920	Unconsolidated materials	Fluvisols, Vertisols, Gleysols, Solonchaks

Source: FAO-UNESCO (1988).

Officer of Kongwa, the has 117,598 cattle, 73,196 goats, 33,896 sheep, 32,592 pigs, and 2,656 donkeys, thus far, farmers can make use of dung from these animals to fertilize the soil and optimize crop yields. However, the fertilization rate of both chemical and organic fertilizers is considerably insufficient.

### Soil sampling

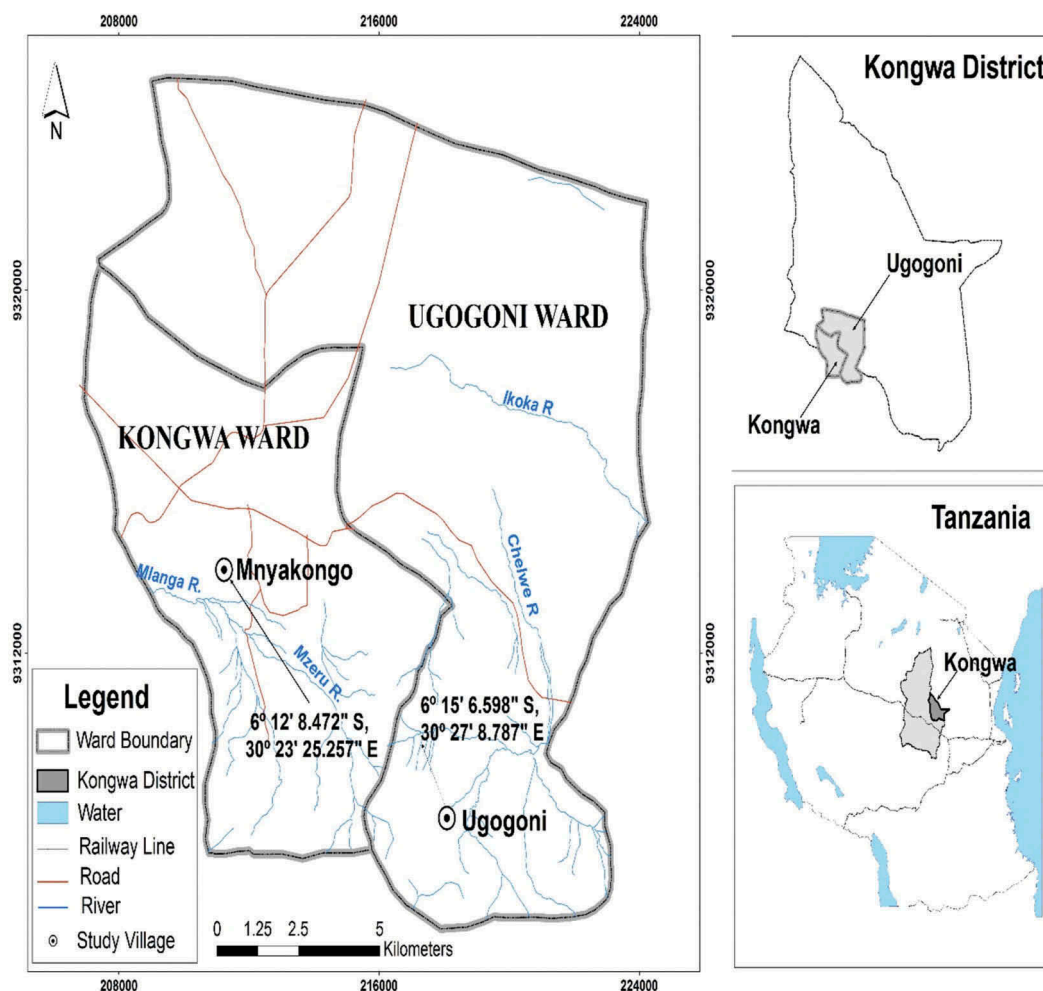
#### Soil sampling and analysis

Soil samples were collected from pits in July 2016. Soil was sampled according FAO guidelines for soil description (FAO 2006). Ugogoni and Mnyakongo villages which represent the highland (910 m a.s.l.) and lowland (900 m a.s.l.), respectively, were sampled for the study (Figure 1). Geographically, the sites were purposively sampled due to their easy accessibility and reported frequent food shortage. Despite the fact that the cropping systems may vary with topography; maize, sorghum, and millet (crops under study) were the major food crops in the area and are mainly produced through monoculture and

rotation. In terms of soil sampling requirements, we selected the two villages because both complied with the needs of the two treatments (i.e., farms with organic fertilization and no-fertilization) and had favorable soil types (Table 1). The village representatives were also consulted in the selection of the sampling sites.

In each village (site), we established two treatments (i.e., farm under organic fertilization, and with no-fertilization) each with two soil depths/profiles (0–20 and 20–40 cm); whereas, for each profile we selected randomly the field to establish four soil ditches ( $W \times L \times D = 40 \times 50 \times 40$  cm). Then, using a 150 mL volumetric soil sampler (6 cm diameter & 5.3 cm height), we sampled four soil cores in each established ditch as seen in Table 2. In this respect, volume-specific samples at 5-cm increments were collected in each soil profile without mixing horizons.

The two soil treatments were defined for more clarification. For the site to qualify as under organic fertilization or no-fertilization, it should have stayed in that status for at least 5 years. All these processes were done



**Figure 1.** Location and sampling positions of the selected villages in the Kongwa District. The study sites are also denoted with latitude and longitudes' degrees.

**Source:** IRA GIS Lab, UDSM: 2016.

**Table 2.** Soil sampling per villages (sites).

Treatment	Depth (cm)	No. of samples (Ugogoni)	No. of samples (Mnyakongo)
Organic fertilization	0–20	16	16
	20–40	16	16
No-fertilization	0–20	16	16
	20–40	16	16
Total		64	64 Grand total = 128

Source: Field Soil Sampling.

in replicate. In this study, sites under organic fertilization are those farms where the application of animal dung (especially cow) has been enormous for a couple of years (over 5 years), whereas those under no-fertilization must have stayed for that couple of years without any fertilization and have pre-experienced soil exhaustion. It was quite simple to get the sites with no-fertilization as more than 70% of the farmers do not use any fertilization.

On the other hand, we had to make an in-depth follow-up when determining and sampling the sites under organic fertilization. Fortunately, in both villages we afforded to get few farmers who have been using organic fertilization for a couple of years. Essentially, they had been doing so because of the availability of animal dungs from their homesteads. Climatically, the area receives a single rainfall regime and, thus, there is a single growing season. On that basis, even fertilization is done once a year at around October to December.

With this respect, we sampled the farms that have been under organic fertilization for more than 5 years and have been receiving at least 28 tn/ha of animal dung per year. The said 28 tons were equivalent to about eight trips of a lorry that carries 3.5 tons of dry animal dung (slightly mixed with soils) in each trip. This quantitative precedence was set by the experienced farmers. On that basis, the process of soil sampling was now concise, accurate, and informative.

Overall, we sampled a total of 128 soil cores in all sites and treatments. Technically, we sampled the maximum depth of 40 cm because most agricultural tillage under small-scale farming ends at that depth. This depth is a bit different from other countries like China where most soils are well developed with profiles far beyond 100 cm (Wang et al. 2010).

Later, the samples were air-dried, sieved, and taken to the laboratory of Sokoine University of Agriculture (Department of Soil and Geological Sciences) for chemical analyses. Soil bulk density was also determined using a soil corer (stainless steel cylinder of 150 cm<sup>3</sup> in volume). Since all soil particles <2 mm were taken for analyses. Retrospectively, crop yields data were gathered in the study area, i.e., from Kongwa District Council and from farmers. These data were crosschecked where necessary for authenticity.

### Laboratory analyses of SOC and other soil nutrients

Soil samples from the field were air-dried, aggregated, and sieved through a 2-mm sieve to allow further chemical analysis (mainly the sieved soil ranged from 2 to 0.002 mm). Thus, additional chemical soil analyses were made using only the soil fraction finer than 2 mm (Homann et al. 1995). The analyses of soils samples based on depths and treatments were done separately in order to make a relevant comparison among them. SOC was measured in the laboratory by the K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>–H<sub>2</sub>SO<sub>4</sub> oxidation method of Walkley and Black (Walkley and Black 1934). The Walkley-Black method gives variable recovery of SOC.

Nonetheless, standard conversion factors of 1.33 for incomplete oxidation and of 58% for “the carbon: organic matter” ratio were commonly used to convert Walkley-Black carbon to the total organic-C concentration, even though the true factors vary greatly between and within soils because of differences in the nature of OM with soil depth and vegetation type (Grewal, Buchan, and Sherlock 1991). On that basis, the mass of C per soil mass (%C), but for upscaling to land units, it was expressed as a C density (Mg C ha<sup>-1</sup> to a 0–40 cm deep).

For an individual profile with  $k$  layers, the equation of Batjes (1996) was used to calculate the amount of organic carbon in the whole soil profile:

$$SOC_d = \sum_{i=1}^k SOC_i = \sum_{i=1}^k \rho_i \times P_i \times D_i \times (1 - S_i) \quad (1)$$

$$SOC_i = \rho_i \times P_i \times D_i \times (1 - S_i) \quad (2)$$

where  $k$  is the number of horizons,  $SOC_i$  is soil organic carbon accumulation (Mg m<sup>-2</sup>),  $\rho_i$  is the bulk density (Mg m<sup>-3</sup>),  $P_i$  is the proportion of organic carbon (gC g<sup>-1</sup>) in layer  $i$ ,  $D_i$  is the thickness of this layer (m), and  $S_i$  is the volume fraction of fragments >2 mm.

However, global calculations of the pool of carbon in the soil are complicated by a number of factors. According to Batjes (1996), these factors include: (1) the still limited knowledge of the extent of different kinds of soil; (b) the limited availability of reliable, complete, and uniform data for these soils; (c) the considerable spatial variation in carbon and nitrogen

concentration, stoniness, and bulk density of soils that have been classified similarly; and, (d) the confounding effects of climate, relief, parent material, vegetation, and land use.

Total soil nitrogen was analyzed using modified Kjeldahl procedure (Wilke 2005). Soil pH was measured by glass electrode using soil-to-water ratio of 1:2. Then, available phosphorus (P) was extracted using Bray 1 method and determined by spectrophotometric procedure (Wilke 2005). Exchangeable potassium was extracted using neutral 1.0 M ammonium acetate and estimated using flame photometer. Apart from (C %), total nitrogen (N %), and available phosphorus (P), other parameters were soil pH (H<sub>2</sub>O and KCl), electrical conductivity (EC), the exchangeable magnesium (Mg), calcium (Ca), potassium (K), and sodium (Na), the cation exchange capacity (CEC), Zn, Mn, Cu, and Fe (Hunt and Gilkes 1992; (Sombroek, Nachtergaele, and Hebel 1993; Cresswell and Hamilton 2002).

### Statistical analyses

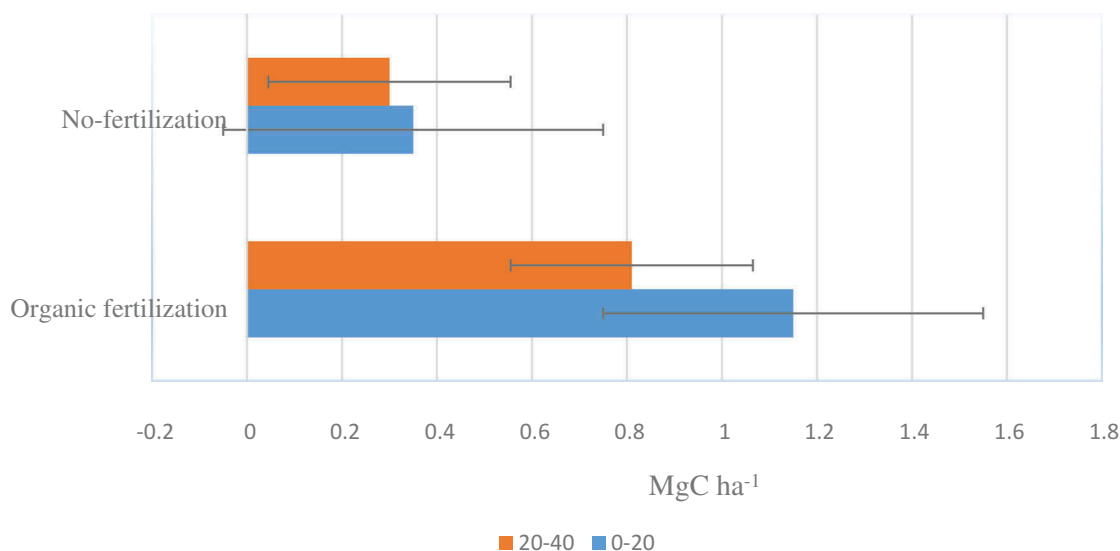
The results were presented as the arithmetic means of two replicates plus standard deviations. The variables were tested for homogeneity of variance and normality, and where necessary, the data were transformed prior to analysis. A Pearson's correlation coefficient

was used to test for significant differences in the accumulation of SOC under different soil treatment. It was also used in testing the correction between crop yields and soil treatments.

## Results

### Soil carbon accumulation

The results showed that SOC was significantly greater in soils under organic fertilization (1.15 and 0.80 MgCha<sup>-1</sup> at soil 0–20 cm and 20–40 cm depth) than under no-fertilization (0.35 and 0.30 MgCha<sup>-1</sup> at 0–20 cm and 20–40 cm), and decreased with increasing soil depth ( $p < 0.05$ ). Under both situations, SOC were highest on the surface (0–20 cm) and diminished with increasing soil depth (Figure 2 and Table 3). These results are in agreement with those by Liu et al. (2017), Haoa et al. (2016), Palm, Blanco-Canqui, and DeClerck (2014), Grand and Lavkulich (2011), Rossi (2009), Lal (2008), Elberling et al. (2007), Ellert, Janzen, and Entz (2002), and Christensen (1988). This happened because manure fertilization was mainly done on the top-soils, and thus, the concentrations of soil nutrients were found at that layer. In soils under no-fertilizations, there were non-significant differences ( $p > 0.05$ )



**Figure 2.** SOC accumulation under both organic and no-fertilizations in different soil depths.

**Source:** Data analyses, 2016.

**Table 3.** Analyses result of soil samples from the study area.

Field ref.	Depth (cm)	No. Samp	TN-Kjeld	OC-BlkW	Ext.P (mg/kg)	CEC (cmolKg <sup>-1</sup> )			
			(%)	(%)	PBry-1	CEC	Ca <sup>2+</sup>	Mg <sup>2+</sup>	K+
Org. Fertil.	0–20	32	0.40	1.15	2.40	36	14.4	5.53	3.23
Org. Fertil.	20–40	32	0.16	0.81	2.10	28	11.2	4.44	2.13
No. Fertil.	0–20	32	0.05	0.35	0.14	34	9.6	3.60	1.31
No. Fertil.	20–40	32	0.03	0.30	0.07	24	5.7	2.50	0.60

Samp.: Sampling; Org. Fertil.: Organic Fertilization; No. Fertil.: No-Fertilization.

**Source:** Lab soil analyses at Sokoine University of Agriculture (SUA), 2016.

between the two horizons because most of the nutrients got lost through monoculture and leaching (Liaudanskiene et al. 2013). In addition, the moisture was higher in the soils with organic than no-fertilization as it was buffered by SOC from leaching (Wang et al. 2010).

Comparatively, SOC under organic fertilization had higher SOC than under no-fertilizations. Animal manure was the major factor for this difference. It was embraced with nutrients more especially carbon and added it in the soil. It was this difference which latter determined crop yields and environmental services.

Similarly, total nitrogen (TN) and phosphorus (TP) were significantly higher ( $p < 0.05$ ) under organic fertilization than in no-fertilizations and decreased from 0.40 and 2.40 Mg (0–20 cm) to 0.16 and 2.10 Mg (20–40 cm), respectively (Table 3). In addition, other important soil nutrients such as calcium ( $\text{Ca}^{2+}$ ), potassium ( $\text{K}^+$ ), magnesium ( $\text{Mg}^{2+}$ ), and sodium ( $\text{Na}^+$ ) behaved the same way (Table 4). The pH value of the soil increased significantly ( $p < 0.05$ ) where manure was applied but remained constant under no-fertilizations (Table 4). The soil pH was neutral as it ranged from 6.5 to 7.5 under both situations. The same trend was observed in Zn, Mn, Cu, and Fe, whereby they decreased under no-fertilization. In addition, high concentrations of these elements were observed at 0–20 cm depth, and had significant ecological implications to crop yields and environmental services (Bokhorst et al. 2017; Liu et al. 2017; Qin et al. 2017). Nonetheless, attention was least given to these trace elements as the study intensely focused on SOC.

It was observed that, continuous cultivation of maize, sorghum, and millet under no-fertilizations, decreased the SOC accumulation by 50% within 5 years of comparison (Figure 2). Later, after 10 years of continuous cultivation, it caused a further loss by about 20% (Glaser et al. 2001; Bationo et al. 2006). Similarly, the lowest TN and TP concentration were found in long-term agricultural fields without manure fertilizations ( $p < 0.05$ ). Correspondingly, the highest cation exchange capacity (CEC), manganese (Mn) and iron (Fe) were significantly optimal under organic fertilizations

but zinc (Zn) and copper (Cu) had no significant changes in both situations, i.e., fertilizations (Table 4). They were not adversely affected by long-term cropping without fertilizations.

The cultivated land appeared to be transient of soil nutrients from the top soils to the bottom layers through leaching (Lal 2008). But it was difficult for uncultivated land which seemed to be compact, and thus, did not allow easy infiltration of soil nutrients. Therefore, organic fertilization seemed to have significant contribution to the accumulation of SOC and other elements in all labile as mentioned before. At the farm level, it was evident that most farmers collected animal manure at the homestead before transporting them to the farm, where sometimes is a bit far.

This homestead collection happens for two major reasons: (1) most of the farmers keep few animals, i.e., less than 10 by average, and thus, even the amount of produced manure is low; (2) farmers aimed to reduce the transport cost whereby the most reliable means of transport seen in the study area is wheel trailer pulled by donkeys and cows. Eventually, the transported manure was deposited in the farms for use.

In addition, soil bulk density (BD) was determined in this study. BD is expressed as the mass of an oven dry sample of intact soil per unit volume (Salifu, Meyer, and Murchison 1999; Soil Survey Staff 2011). It is very important physical property which is needed for mass to volume or area conversions of soil properties. It is essential for the assessment of soil C stocks and nutrient pools (Lal 2008) and, in most cases, is the mandatory measuring unit for soil C assessment in CDM A/R (Clean Development Mechanism Afforestation/Reforestation) accounting (Vogel 1994; UNFCCC 2007).

BD was less under organic fertilization than under no fertilization (Hunt and Gilkes 1992; Salifu, Meyer, and Murchison 1999; Cresswell and Hamilton 2002). This happened probably because there were more OM concentrations under organic fertilization than in the counterpart. In addition, the sub-surface layer in both conditions had higher BD than beneath. This happened because the bottom soil layers had reduced OM,

**Table 4.** Analyses result of soil samples from the study area.

Field reference	Depth (cm)	No. Samp	Soil pH (1:2.5)		EC 200 $\mu$ S/cm	Zn mg/kg	Mn mg/kg	Cu mg/kg	Fe mg/kg
			(in $\text{H}_2\text{O}$ )	$\text{CaCl}_2$					
Org. Fertil.	0–20	32	5.48	6.11	39	0.89	6.97	0.40	17.98
Org. Fertil.	20–40	32	6.18	6.21	36	0.83	4.13	0.25	15.98
No. Fertil.	0–20	32	6.80	5.25	32	0.34	2.81	0.04	13.46
No. Fertil.	20–40	32	6.58	4.57	30	0.32	2.20	0.04	10.47

Samp.: Sampling; Org. Fertil.: Organic Fertilization; No. Fertil.: No-Fertilization.

Source: Lab soil analyses at Sokoine University of Agriculture (SUA), 2016.



aggregation, root penetration, and compaction of soil from the above (Mishra et al. 2017; Cresswell and Hamilton 2002). In whole, both fertilizations had low BD because the samples were sieved in less than 2-mm diameter and thus, they had fine texture. Therefore, the soil had a recommendable BD for agriculture (Soil Survey Staff 2011; Hunt and Gilkes 1992). Then, SOC accumulation was calculated by the following formula:  $\text{SOC} = \text{Depth (cm)} \times \text{Bulk density (gcm}^{-3}\text{)} \times \text{Organic carbon (\%)}$

Hence, SOC (0–20 cm)

(A) under organic fertilization =  $20 \text{ cm} \times 1.1 \text{ gcm}^{-3} \times 1.15 \text{ MgC ha}^{-1} = 25.3 \text{ Mg ha}^{-1}$

(B) Under no-fertilization =  $20 \text{ cm} \times 1.2 \text{ gcm}^{-3} \times 0.35 \text{ MgC ha}^{-1} = 8.5 \text{ Mg ha}^{-1}$

The accumulation of SOC decreased basing on soil management and depths. These results of the present study provide an accurate assessment of SOC accumulation in semiarid areas under the auspices of organic fertilizations and without it (IPCC 2003). It highlights the potential activities that could significantly contribute to the accumulation of SOC and other related nutrients. It is this soil management that supports the level of soil C mineralization and, therefore, forming an important aspect for soil fertilization, carbon sequestration, and adaptation to climate change impacts especially in the arid and semiarid environments.

### Crop yields

Crop yields from organic fertilization were compared with those without fertilizations. The yields for 7 years from either under organic or no-fertilizations was enough to determine the differences. This empirical study realized that there were significant difference in yields of maize, sorghum, and millet under fertilization and no-fertilization. The average yields for all crops was about  $1.6 \text{ tn ha}^{-1}$  under organic fertilization and  $0.6 \text{ tn ha}^{-1}$  under no-fertilization. Therefore, yields were significantly higher under organic fertilizations than no-fertilizations (Table 5). Maize yields ranged from  $1.5$  to  $2.2 \text{ tn ha}^{-1}$  while both sorghum and millet had  $1.1$ – $1.7 \text{ tn ha}^{-1}$  (Table 5). Maize that appeared to be the most favorable and staple food (United Republic of Tanzania 2014; Mkonda and He 2017a) responded well to organic fertilizations than sorghum and millet, but was adequately affected under no fertilizations (Table 5). Sorghum and millet appeared to be tolerant to nutrient-deficiency stress because they had almost a similar trend in all 5 years (Table 5). However, this did not guarantee optimal yields as they had very low ( $0.5$ – $0.7 \text{ tn ha}^{-1}$ ) yields at as seen in (Table 5).

**Table 5.** Correlation ( $r$ ) between average crop yields ( $\text{tn ha}^{-1}$ ) and soil treatments in the sampled villages.

Year	Organic fertilization				No-fertilization			
	Maize	Sorghum	Millet	$r^*$	Maize	Sorghum	Millet	$r^*$
2010	1.5	1.1	1.1	0.35	0.4	0.6	0.5	0.27
2011	1.6	1.2	1.1	0.37	0.4	0.6	0.5	0.27
2012	1.7	1.5	1.4	0.42	0.8	0.5	0.5	0.29
2013	1.6	1.4	1.6	0.51	0.5	0.5	0.5	0.18
2014	2.2	1.7	1.6	0.56	0.6	0.6	0.6	0.23
2015	2.1	1.6	1.6	0.58	0.6	0.5	0.5	0.25
2016	2.2	1.7	1.6	0.63	0.6	0.7	0.7	0.27

Source: Field Data Analysis, 2016.

$r^*$  indicates Pearson correlation of the data (i.e., fertilizations and the overall crop yields) at 5% level of significance.

### Discussion

This study establishes a discussion on the quantitative assessment of SOC under different soils treatments as seen in Tables 3 and 4 (IPCC 2000a; Deckers 2001; Roose and Barthes 2001; Lal 2004; Lal 2008; Rossi 2009; Wang et al. 2010; Hao et al. 2016). This is because in the study area there was no any study that has established the accumulation of SOC which would be a baseline study for the forthcoming studies. Thus, among other things, the present study serves as a baseline. It has revealed that here were significant correlations between the accumulation of SOC and soil managements ( $p < 0.05$ ). Figure 2 indicates that there were more SOC in farms under organic fertilizations than under no-fertilization. This considerable increase in SOC was greatly attributed by the application of animal dung, i.e., cow in the farms (organic fertilization).

Again, the accumulation of SOC was on the top soils (0–20 cm) than sub-soil (20–40 cm) because most of these soil organic managements are implemented in that top layer (Tables 3 and 4). This was even evident in the section of SOC calculation of this empirical paper. IPCC (2003) recommends the calculation of carbon densities for a given soil depth, e.g., 0–30 cm, 30–100 cm more especially when most SOC is contained in the sampling depth. This is done because sampling may miscalculate the SOC in high bulk density (BD) as BD may be affected by tillage. As a solution, Ellert, Janzen, and Entz (2002) recommended the expression of SOC amount on the equivalent mass basis.

Optionally, volumetric measurements can be corrected by adjusting the sampling depth. This involves the sampling of smaller depth in heavier soils or greater depth in light soils. In the present study, we calculated the BD and SOC stock to a fixed depth of 20 cm for each horizon. We sampled a maximum soil depth of 40 cm because this is the considerable depth in which agricultural practices take place. This is good especially for the small-scale farming which mostly uses hand hoe. Thus, this particular depth

determined the influence of soil management to SOC accumulation (Baldock 2007).

This is fairly important because it increases the capacity of nutrients uptake by plants. To support this assertion, Kalhapure, Shete, and Dhonde (2013) and Nyadzi et al. (2006) confirmed that soil's organic management increases the amount of soil mineralization more especially soil C and, therefore, increasing soil fertility. In the study site, the major source of organic fertilization was manure from sheep, goats, and donkeys. Hence, the number of animal determined the magnitude of fertilization. In the area, the most herded households had an average of 30–50 cattle, whereas the least herded were averages at <10 cattle. Therefore, there were major correlations between the number of herds and the acreage under organic fertilization.

On the other hand, there had been a serious decline of soil fertility under no-fertilizations (Figure 2). This study found the highest decline of crop yields was due to continuous cultivation without fertilizations, a situation that had exhausted high quantity of important soil nutrients (Figure 2). This confirms the findings from other studies which indicated high decline of soil fertility under a given soil management (Hartemink 1997; Glaser et al. 2001; Bationo et al. 2006; Haoa et al. 2016) just to mention a few. Under such a situation, important soil nutrients such as carbon, nitrogen, potassium, and phosphorus declined due to removal of cations. In these farms, plants had no sufficient nutrients for their growth and, thus, poor yields were obtained as seen in Table 5 above. Permanent cropping and continuous cultivation resulted into a negative balance of soil nutrients that need to be offset by soil nutrient pools (Hartemink 1997; Mkonda and He 2017b). Under such a situation, even the little elements which were difficult to be weathered were now depleted easily. This eventually affected crops yields and subsequently exacerbated abject poverty among the farmers.

Under organic fertilization, the ability of OM to retain cations for plant utilization while buffering them from leaching was higher than in area without fertilizations (Yao et al. 2010). The cation exchange capacity (CEC) of OM is due to negative charges created as hydrogen (H) removed from weak acids during neutralization (IPCC 2000a). OM also reduces or buffers the change of pH in the soil when acids or bases are added in the soils (IPCC 2000a). On that basis, crop yields would improve when other factors were constant (Henry et al. 2009; Mkonda and He 2017c).

The difference in water content of soil between the two sites (soils under organic and no-fertilizations) brought significant insights on the same (Mkonda and He 2017d). Fertile soils appeared to have high

retaining water capacity than that under no-fertilizations because of high OM (under organic fertilization) buffers moisture that can get lost through leaching (Deckers 2001; Duan et al. 2011; Mkonda and He 2017c). Thus, when other factors were constant, agricultural fields with manure had a high degree of moisture concentration than under no-fertilizations, thus optimizing crops yields on the former than the latter (Duan et al. 2011). Results from informative interviews and household survey supported the results from analyses (Figure 2) as they informed that more maize, sorghum, and millet yields were obtained under organic fertilization than under no-fertilization, albeit, all sites were hit by climate change impacts. They were assertive that, organic fertilizations were potential for crop yields.

By SOC being resilient from losing moisture and fertility, the agricultural fields under organic fertilizations acted as a sink of atmospheric carbon and thus mitigating climate change impacts by seizing carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) which are the first, second, and third largest greenhouse gases, respectively, in contributing to global climate change (IPCC 2013; Kumar and Nair 2011). Mitigation of these gases can further increase resilience of the farmers in this era of global climate change. The studies by Reeves (1997) and Rossi (2009) have similar observation on the same. However, Munishi and Shear (2004) specified that the amount of sequestered C is equivalent to that found in biomass ( $p < 0.05$ ). Thus, soil degradation leads to C exit to the atmosphere and for it to be seized back, we need to have sinks (plants).

To restore such a situation, organic fertilization has shown to be a good option (Kalhapure, Shete, and Dhonde 2013; Parras-Alcántara et al. 2016; Rodrigo-Comino et al. 2016). It increases soil fertility and resumes the biological functioning of important soil microorganisms such as mycorrhizae fungi, optimizes photosynthesis, nutrients uptake, growth of shoots and roots (Wang et al. 2010; Smith et al. 2011; Galati et al. 2016). Similarly, these fertilizations facilitate plant growth and resistance to pathogens which increases crop yields (Yao et al. 2010). At ground level, this was supported over 70% of the farmers who applied manure and got adequate yields.

In addition, an interview with District Agricultural and Livestock Officer (DALDO) confirmed that in areas where animal manure, straws, or a combined animal + straws are applied, the yields of maize, sorghum, and millet (food crops) has been optimal. Therefore, the adoption of organic fertilization is quite important because it leads to optimal crop yields which are a major source of livelihood among the farmers in the study area. The findings of this study have similar observations with some authors but slight differences with some others. The main

reason for this difference is due to different soil types, climate, intensity of agroecosystems, depth for soil analyses, and parent materials just to mention a few (Christensen 1988; Davidson 1994; Batjes 1996; Bationo et al. 2006) who generally obtained SOC between 1.5 and 3.4 MgC in 0–30 depth. They mostly obtained it under tropical climates, whereas the present study did so in the semiarid climate.

Under natural condition, rainfall plays a significant role in the process of accumulating carbon in the soil. The change in moisture regime affects the decomposition of biomass (IPCC (Intergovernmental Panel on Climate Change) 2000a). Amount of rainfall determines the amount of SOC that accumulate or exit (Elberling et al. 2007). Extremely low rainfall leads to excessive drought that limits the production of plant biomass and formation of OM in the soil, whereas high rainfall leads to high water content of the soil and eventually the decrease in decomposition rate of OM and, thus, further increasing SOC (Glaser et al. 2001; Baldock 2007; Mkonda and He 2017b). In whole, Wang et al. (2010) realized that there is an exponential correlation between SOC accumulation and precipitation. In addition, the increase in temperature and decrease in rainfall are likely to reduce the Net Primary Productivity (NPP) and Net Ecosystem Productivity (NEP) albeit its magnitude may not be easily quantified. The areas experiencing drought due to dry spells and increased evaporation have a lesser possibility to accumulate SOC (Hartemink, Veldkamp, and Bai 2008). Usually, SOC accumulation increases from warm to cold and from dry to wet locations (Roose and Barthes 2001; Usuga et al. 2010; Yao et al. 2010). Therefore, there is a significant correlation between climate and SOC accumulation (UNFCCC (United Nations Framework Convention on Climate Change) 2007).

Potentially, the present study found that agricultural fields under organic fertilization had notably higher yields at 1.6 tn ha<sup>-1</sup> than 0.6 tn ha<sup>-1</sup> under no-fertilization (Table 5). This was because of the soil nutrients' availability in the former than the latter. Likewise, crop yields have been increasing significantly overtime under organic fertilization (Table 5). Similarly, organic fertilizations conserved the functioning of biological condition of the soil more, especially the mycorrhizae fungus and plant root synergies (Smith et al. 2011). The study by Wang et al. (2010) also found that there is exponentially positive correlation between SOC accumulation and biological functions. Thereby, an increased accumulation of C in the soil will accelerate microbial processes, as will warm and moist the soil (Davidson 1994).

For the assessment of the production potential of each crop, maize, sorghum, and millet were compared (Mkonda and He 2017a). They responded

differently under different fertilizations, cropping systems, and economic potentials. All crops were optimal under organic fertilizations as they gave maximum yields at 2.2, 1.7, and 1.6 tn ha<sup>-1</sup> for maize, sorghum, and millet, respectively. However, correspondingly they gave fewer yields under no-fertilization at 0.4, 0.5, and 0.5 tn ha<sup>-1</sup> (as minimum yields) for maize, sorghum, and millet, respectively. Apart from the SOC content, the productivity potentials of the particular agroecosystem were coupled by the sufficient contents of N, P, Ca<sup>2+</sup>, Mg<sup>2+</sup>, K<sup>+</sup>, and other microelements (Tables 3 and 4).

Subsequently, there were significant differences ( $p < 0.05$ ) in crops yields under different cropping systems. Maize had outstanding yields when intercropped with leguminous crops, i.e., lablab compared with sorghum and millet. In addition, sorghum did well under long-term monoculture without fertilization than other crops. Under favorable weather, in the mixed cropping of the three crops; maize did better than others whereas sorghum was best under stressed environment, i.e., drought. Thus, under poor soil, sorghum needs to be adopted as it gives optimal yields despite such unfavorable condition.

Economically, there were no significant differences in the production process of the three crops. This is because all crops used about the same cropping systems and preparation costs. On the other hand, the yield demands of the three crops appeared to have no significant differences ( $p > 0.05$ ); however, during food shortage maize appeared to have high demand pressurized by the demands at national level. Under high yields, maize was sold at \$0.5 per kg, whereas sorghum and millet were sold at around \$0.3 per kg. However, during food shortage this price doubled or trebled especially for maize. We visited in some maize stores where maize is sold and realized that, there were significant different ( $p < 0.05$ ) in the price during harvest and at least 6 months after harvest. The price of maize during harvest was a bit affordable (around \$0.3–0.4 per kg) than during scarcity when sometimes reaches to about \$1 per kg. This price was extraordinary high to most food destitute. Therefore, economically, maize had high demand compared to sorghum and millet.

Here, we can summarize by confirming the hypothesis (H<sub>1</sub>) that the accumulation of carbon and other important soil elements depended on depth, types of agronomy, and level of organic fertilization (soil organic managements). It is apparently definite that in areas with organic fertilization, the level of soil C is high and, therefore, increases soil fertility for crop production. We have also seen the significant differences in crop yields between the two soil managements. Basing on that, it is worthwhile to advise farmers to adopt organic fertilization in their farming because of the fore-mentioned potentials especially

curbing frequent food shortages in most semiarid of sub-Saharan Africa. This only happens when the said advantages (i.e., SOC) are quantified and established to the extent that a certain amount of SOC can suffice the required crop production.

## Conclusion

Therefore, the present study has confirmed the hypothesis (H<sub>1</sub>) as all hypothesized aspects have been confirmed. On that basis, it has met its objectives as it has revealed the differential accumulation of SOC and its related aspects under organic and no-fertilization, different crop yields, and provision of environmental services under the two soil management practices. The results from the data analyses have supported the achievement the study objectives and the tested hypotheses. Therefore, intensive organic fertilizations seem to be a sustainable solution to the poor yields in this semiarid environment, where there is increasing variability of rainfall amount and pattern. This study can be appropriate across different soil types, climatic regions, vegetation types, and various agroecosystems.

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