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Burning, biomass removal and tillage effects on soil organic carbon and nutrients in seasonal wetlands (Dambos) of Chiota smallholder farming area, Zimbabwe

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Seasonal wetland (dambo) cultivation in smallholder farming areas is important because it improves household food security. However, most farming practices, such as burning of vegetation and conventional tillage in dambo gardens, may reduce soil organic carbon (SOC) and nutrient dynamics. We evaluated the effects of simulated burning, vegetation clearing and clipping, and conventional tillage in dambo gardens on SOC, nutrient contents and biomass production over a 3-year period. The results showed that clearing and clipping of vegetation and conventional tillage reduced SOC, soil nutrient contents and biomass yields, while burning increased SOC and soil nutrient contents. For the 0–10 cm depth, conventional tillage, clearing and clipping resulted in a 37%, 34% and 18% decrease in SOC, respectively, after three seasons, burning resulted in a 25% increase in SOC, while there were no changes in the control after 3 years. For the 0–40 cm depth, the average change in SOC was 32%, 25% and 16% for conventional tillage, clearing and clipping, respectively. Locally and regionally, conventional tillage, clearing and clipping reduce SOC, nutrient contents and biomass production in dambos. Though annual burning increased SOC and nutrient contents in the short term, the long-term effects are uncertain, hence there is a need for long-term studies.

Keywords: dambo (seasonal wetland); conventional tillage; soil organic carbon; nutrient contents; biomass removal

Introduction

Dambos are seasonally saturated, grassy, gently sloping valley floors, which are inundated for months during rainy seasons (Acres et al. 1985; Boast 1990). The physical potential of dambos in sub-Saharan Africa can conservatively be estimated at 135 million hectares (ha) (FAO 1998; SADC 2001), and estimates based on vegetation maps of Africa put dambo-occupied landscapes at 20% of land surface of the elevated Central African Plateau (Acres et al. 1985; Bullock 1992). In Zimbabwe, dambos occupy an estimated 1.28 million ha, (Whitlow 1985). In their natural state, dambos store significant amounts of soil organic carbon (SOC), because they are saturated for a greater part of the year; hence, they protect SOC from microbial oxidation. As a result, dambos have more SOC stocks when compared to most savannah ecosystems. Several researchers have reported dambo SOC contents ranging from 0 to 25 g kg^{-1} among them Grant

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(1995), Bell et al. (1987), Bell and Roberts (1991), von der Heyden (2004) and Nyamadzawo et al. (Forthcoming 2013a). The SOC contents reported in dambos are higher compared to average SOC contents in upland sites of 4–10.0 g kg^{-1} (Bell & Roberts 1991; Grant 1995; Nyamadzawo et al. Forthcoming 2013a).

In Zimbabwe, seasonal wetlands (dambos) have experienced intensive cultivation over the past 30 years, as a response to climate change and variability, which have resulted in perennial crop failures in upland fields. In Malawi, Mloza-Banda (2005) suggested that low upland productivity partly influenced the exploitation of dambos. Dambos are a valuable resource for agricultural purposes due to their widespread occurrence, availability of soil moisture for long periods, and high fertility; thus, they are an important resource, especially in semi-arid to arid regions, which are prone to droughts (Mazambani 1982; McCartney et al. 2005). In some smallholder farming areas of Southern Africa, farmers have actually abandoned cultivating uplands, in preference to dambos, because of poor yields which are a result of recurring droughts and low soil fertility (Mloza-Banda 2005; Kuntashula et al. 2006; Nyamadzawo et al. Forthcoming 2013b). In many developing countries, particularly in Africa, wetlands, such as dambos, have been perceived by some as the ‘new frontier’ for agriculture (Wood and Dixon 2009), as they provide a buffer against crop failures, in addition to their suitability to have multiple cropping in a single year. For poor rural households that are short of food, dambos can provide a life-saving safety net and provide a development opportunity which can lead them out of poverty (McCartney et al. 2010).

In cultivated dambos, prescribed burning, biomass removal using hoes, or clipping and conventional tillage are frequently used (Nyamadzawo et al. Forthcoming 2013b), and these practices potentially affect SOC, soil nutrient contents and vegetation productivity. In dambo gardens, smallholder farmers burn to clear grass in preparation for tillage. In addition, farmers burn to control pests and diseases and improve soil fertility. For herbaceous annuals, vigorous growth usually occurs after fires, as fires release a portion of nutrient contents previously held in plant biomass and quickly return it to the soil and stimulate new growth (Shah 2012). While studies investigating the role of fire on soil carbon have been conducted in forested and grassland ecosystems, research in wetlands is limited, e.g., Medvedeff et al. (2003), Gu et al. (2008), Qian et al. (2009), Zhao et al. (2012) and these were mostly in temperate wetlands. There are no available data on the impacts of fires on SOC and soil nutrient contents in tropical wetlands, including seasonal wetlands (dambos) of Central and Southern Africa.

Besides biomass removal through burning, grazing and clipping are frequently used in dambos by smallholder farmers. Vegetation is often removed or cleared in preparation for conventional tillage using hoes, while sickles are often used for clipping vegetation. Removed biomass is used as fodder supplement, which is carried to the livestock pens or is used as mulch in vegetable production, while some is burnt. Several studies have simulated the effects of biomass removal on wetland plant species. Matheson et al. (2002) reported reduced shoot and root growth of the vegetation 1 month following clipping in *Glyceria declinata* in New Zealand. In Australia, Crosslé and Brock (2002) simulated grazing using clipping and observed that in some species, biomass and reproduction increased, for some biomass decreased and reproduction increased, while for some, there was reduced biomass and reproduction following clipping. These changes to vegetative and reproductive output have the potential to alter SOC accumulation in the soil. However, there is no available literature on the effects of different biomass removal practices on SOC, soil nutrient contents, plant species diversity and biomass productivity in seasonal wetlands, especially in Southern Africa.

A study by Nyamadzawo et al. (Forthcoming 2013b) reported that in dambo gardens, 99% of the farmers cultivated their land either using an ox drawn plough (85%) or using the hoe for digging (14%). Cultivation exposes large SOC stocks stored in dambos to microbial oxidation and this increases SOC breakdown. Conventional tillage of dambos can potentially reduce SOC and nutrient contents of soils. Grant (1995) reported that dambo cultivation resulted in a 21–23% decline in SOC after cultivation for between four and seven years. Lal (2007) reiterated that the depletion of the SOC pool can be exacerbated by practices such as soil drainage, conventional tillage, biomass burning and other processes. Even though some farmers add manure to replace lost SOC and nutrient contents in dambo gardens, results from trials at Rothamstead suggested that large inputs of manures (>35 t ha^{-1} year^{-1}) over long period of time (>100 years) may be required to observe an increase in SOC contents (Edmeades & Douglas 2003). Such high amounts of inputs are not available in the resource constrained smallholder farming areas.

In addition to reducing SOC in dambo gardens where conventional tillage is used, the major challenge is the increase in soil erosion (Dambo Research Unit 1987; Mharapara et al. 1998). During the colonial times in Zimbabwe, dambo cultivation was prohibited due to erosion hazards associated with their utilization (Rattray et al. 1953), and also because the land capability classification system of Zimbabwe places dambos in Class V, which denotes that, the soils are not suitable for cultivation (Ivy 1981). Currently, dambos continue to degrade at an alarming rate as their cultivation is intensified and farmers are encroaching on more fragile areas. Such encroachment through cultivation in the absence of technical guidance or traditional experience, which has since been forgotten by many, has further increased damage to the dambo ecosystem (Mharapara et al. 1998)

Although the cultivation of dambos brings significant benefits in terms of food security and income, poor cultivation practices can result in deleterious environmental impacts (e.g., reduced soil fertility, reduced biomass additions and reduced SOC, changes in vegetation species), which have negative consequences for livelihoods (McCartney et al. 2010). Disturbances from conventional tillage, fires and other anthropogenic activities can modify the physical environment and alter plant species abundance (Vasey et al. 2005). The depletion of SOC pool has an adverse feedback mechanism, as it increases atmospheric carbon dioxide (CO_2) concentrations. A severe depletion of the SOC pool leads to decline in soil quality, poor structural stability, negative water balance exacerbated by high losses caused by severe run-off, soil erosion and low species diversity. Decline in soil quality reduces net primary productivity (NPP), decreases the quality and quantity of biomass returned to the soil, and this further accentuates the depletion of SOC pool (Lal 2007). Therefore, understanding the effects of farmer management practices on SOC, soil fertility, biomass production and changes in species diversity is important, if necessary interventions are to be put in place to avoid degradation of cultivated seasonal wetlands. Thus, the objective of this study was to evaluate the short-term effects of biomass removal practices (burning, clearing, clipping) and conventional tillage on SOC, soil nutrient contents, biomass productivity and species composition in dambo gardens.

Material and methods

Study site

This study was carried out in Chiota smallholder farming area. Chiota is located 70 km south-east of Harare (31° 05′ S; 18° 11′ E), receiving average rainfall between 700 and 800 mm with a mean annual temperature of 18.6°C. The soil at the study site was classified as sandy loam soil (*Haplic Lixisols)* (FAO 2006), which is derived from granite. Dambos occupy an estimated 19,500 hectares (ha), which is 29.6% of land area (65,800 ha) in Chiota (Bell & Roberts 1991). Chiota is representative of dambos that are found throughout the central watershed of Zimbabwe. In the smallholder farming area of Chiota, mixed farming, which involves cropping and animal husbandry, is practiced. Livestock grazing is mainly concentrated in the uplands during the rainy season and dambos during the dry season, because in dambos, the grass will continue growing using residual moisture. Dambos have three major functions, which are, garden cultivation, pastures for grazing and water supply for both livestock and domestic use (Dambo Research Unit 1987).

Experimental design and soil sampling

The experiment was located in Kashumbamhere village, in Mr Ruseres' dambo garden, the area of which was approximately 1 ha. The garden was located in the mid-slope catena position of the dambo, which is seasonally saturated (Dambo Research Unit 1987). The practices that were evaluated were identified during an earlier study which was carried out in 2010 (Nyamadzawo et al. Forthcoming 2013b). Plots of size 1 m × 3 m were established in 2010 in an area which was in its natural or fallow state and had not been tilled. Though small, the plots used were meant to simulate the practices used in farmer gardens. The farmer practices that were evaluated were annual burning; clearing, clipping and conventional tillage. Annual burning involved setting alight the vegetation in the plots during the fire season (August to November), when dambo vegetation is dry. Clearing involved the removal of all the vegetation from the plots using hoes and the biomass was removed from the plot. Clipping involved the cutting of vegetation using sickles at 5 cm above ground level and all the clipped biomass was removed. Clipping allowed re-sprouting of vegetation, while for clearing, there was complete removal of vegetation and there was no regrowth from previous vegetation. Conventional tillage involved digging up to 20 cm depth using a hand hoe. Under conventional tillage, some of the vegetation was incorporated into the soil. In addition, a control was also included, where vegetation was undisturbed and was left in its natural state. A randomized block design was used and all treatments were replicated three times (Figure 1). A distance of 1 m was allowed between blocks. A total of 60 samples were collected from the plots (4 depths × 5 treatments × 3 replicates), in 2010, for initial soil characterization. Samples were collected from 0–10, 10–20, 20–30 and 30–40 cm depths using a Dutch auger. Soil samples were

		Replicate 1		
Burnt	**Clipping**	**Cleared**	**Control**	**Conventional tillage**
		Replicate 2		
Conventional tillage	**Control**	**Burnt**	**Clipping**	**Cleared**
		Replicate 3		
Cleared	**Clipping**	**Conventional tillage**	**Control**	**Burnt**

Figure 1. Experimental design and layout of plots at the study site.

similarly collected 1, 2 and 3 years after establishment of the trial (2011, 2012 and 2013, respectively).

Sample analysis procedures

Soil characterization included analysis of SOC, nitrogen (N), available phosphorus (P) and exchangeable potassium (K), magnesium (Mg) and calcium (Ca). The samples were air-dried before they were finely ground to pass through 2 mm round hole stainless steel sieve for N, P and K determinations and further finely ground to pass entirely through 0.5 mm sieve for SOC determination. SOC was determined using the modified Walkley–Black procedure (Nelson & Sommers 1992). Total nitrogen (N) was determined using the Kjeldahl method (Anderson & Ingram 1993) and available phosphorous (P), exchangeable Ca, Mg and K were all determined using the Merlich-3 method. Phosphorous was analysed using the Murphey and Riley method and colour developed was read at 660 nm wavelength. Calcium and Mg were analysed using the atomic absorption spectrophotometer (Varian AAS 50, Varian Australia Pvt Ltd, Mulgrave, Australia). Potassium was analysed using the flame photometer (Okalebo et al. 1993). Soil texture was determined using the sedimentation hydrometer method (Bouyoucos 1962). Soil pH was measured using a Mettler Toledo pH meter (Mettler Toledo Grpou, Schwerzenbach, Switzerland), in a 1:2 soil:deionized water suspension (Miller & Kissel 2010).

Total above-ground standing biomass at the end of the rainy season was measured using 0.5 m × 0.5 m quadrants in April 2013. Each plot was sampled by randomly throwing the quadrants into the plots. The plants within the quadrant were collected and separated according to species. The samples were then oven dried at 60°C for 48 hours, after which each sample was weighed. The different species were identified with the assistance of National Herbarium staff in Harare. The number of different species per quadrant was used to calculate species richness.

Data analysis

Analysis of variance (ANOVA) for SOC, nutrient contents and biomass production across different management practices were carried out using Genstat statistical package (VSN 2011). Separation of means was done using least significant differences procedure at $p < 0.05$, where there were significant treatment effects on the measured variables.

Results

Initial site characterization classified dambo soils as sandy loam (*Haplic Lixisols,* FAO 2006) and the soil textural analysis showed that 74% was sand, 11% silt and 15% clay. The sand content ranged between 67.8% and 82.7% and increased with depth, while clay and silt content decreased with depth (up to 40 cm). The clay contents ranged between 9.1% and 19.2%, while silt was between 8.3% and 13.1 %. The average pH was 5.4 and pH was not significantly different among treatments and depth. At the beginning of the experiment in 2010, the average dambo SOC content was 25.6 g kg^{-1}, and 143 Mg ha^{-1} SOC stocks for the 0–40 cm depth. The initial SOC concentrations (in 2010) were 49, 36, 17 and 11 g kg^{-1} for the 0–10, 10–20, 20–30 and 30–40 cm depths, respectively (Table 1).

Dambo disturbance through conventional tillage, clearing using hoes and clipping of vegetation resulted in a decrease in SOC. Conventional tillage resulted in the highest per cent decline in SOC (18–37%), relative to the control (Table 2). Clearing resulted in

Table 1. Initial SOC and soil nutrient concentrations in 2010.

Depth (cm)	0–10	10–20	20–30	30–40	SED
Initial SOC (g kg^{-1})	4.9	3.6	1.7	1.1	0.1
Total nitrogen (g kg^{-1})	3.0	2.1	1.7	1.0	0.7
Available phosphorus (μg g^{-1})	3.6	3.1	3.0	2.5	1.0
Exchangeable calcium (μg g^{-1})	900	800	450	350	68.0
Exchangeable magnesium (μg g^{-1})	340	250	225	219	11.6
Exchangeable potassium (μg g^{-1})	90	80	44	40	7.0
C:N	13.3	11.9	11.8	11.0	

Note: C:N = carbon to nitrogen ratio, SED = standard errors of differences of means.

Table 2. Changes in SOC after 3 years, following various disturbances in dambo garden soils.

	0–10 cm	10–20 cm	20–30 cm	30–40 cm	Average
	Initial SOC (g kg^{-1})				
	4.9	3.6	1.7	1.1	1.1
Treatment	SOC after 3 years (g kg^{-1})				
Conventional tillage	3.1	2.4	1.1	0.9	1.8
Control	4.8	3.4	1.6	1.1	2.7
Cleared	3.2	2.7	1.3	1.0	2.0
Clipping	4.0	3.1	1.3	1.0	2.4
Burning	6.1	5.6	4.0	1.0	3.8
	Change in SOC after 3 years (%)				
Conventional tillage	−37.1	−34.7	−38.2	−18.2	−32.2
Control	−3.1	−5.6	−5.9	0.0	−3.6
Cleared	−34.1	−25.6	−25.9	−13.6	−24.8
Clipping	−18.0	−13.9	−24.7	−9.1	−16.4
Burning	24.9	54.4	40.0	−9.1	27.8

between 14% and 34% decline in SOC after 3 years (Table 2). The greatest decline in SOC occurred in the first year (Figure 2b). However, SOC concentrations under clipping and clearing conditions were not significantly different from that of the cultivated treatment (Figure 2b–d). Annual burning over 3 years resulted in a significant increase in SOC for the 0–30 cm depth (Table 2). For 2011 and 2012, SOC concentrations were largely not significantly different among treatments, but significant differences were evident in 2013 (Figure 2b–d). For all treatments, SOC decreased with increasing depth (Figures 2a and 4a). However, during the study period, there were no significant differences in SOC among treatments at the 30–40 cm depth (Figure 3a).

Concentrations of soil nutrients at the beginning of the experiment are shown in Table 1. Total N varied significantly ($p < 0.05$) among treatments and decreased with increasing depth (Figures 2b and 4b). Burning resulted in an increase in N concentrations and this was followed by clipping and clearing in the second year (Figure 3b). In the third year, burning still maintained higher N concentrations, followed by conventional tillage (Figure 4b). The total N in the second year (Figure 2b) was greater than that in the third year

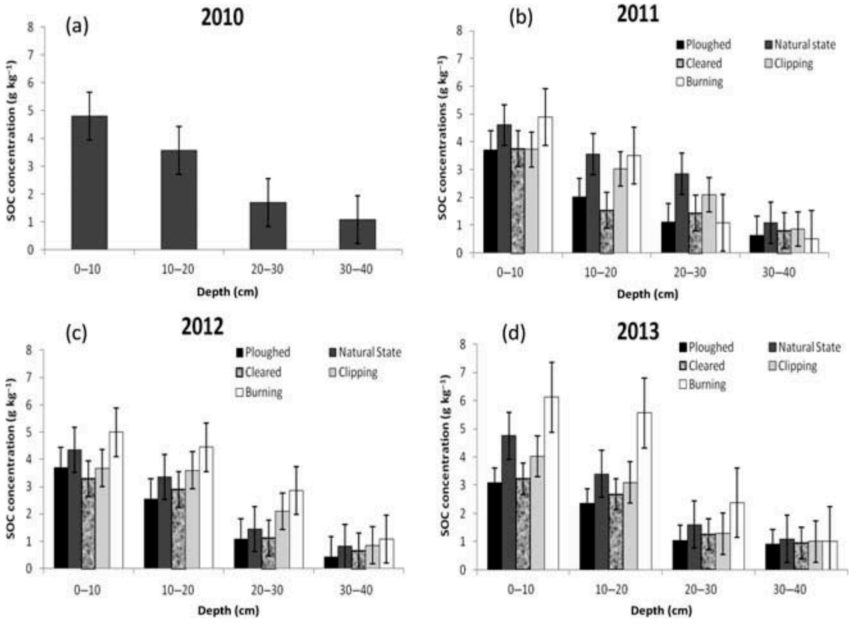

Figure 2. Changes in SOC concentration (g kg^{-1}) in dambos subjected to different disturbance regimes for (a) 2010 (b) 2011 (c) 2012 and (d) 2013. Vertical bars are standard error bars. CT = conventional tillage.

(Figure 4b). Although dambos have low total N in their natural state, cultivation resulted in a further reduction of total N. Nitrogen varied significantly with depth, and the highest N concentrations were in the 0–10 cm depth and least in the 30–40 cm depth (Figures 3b and 4b), as expected. SOC had a good correlation with total nitrogen, $R^2 = 0.71$ (second year) and 0.67 (third year).

In the second year, available P concentrations were significantly different ($p < 0.05$) among treatments (Figure 2c). In the second year, tilled plots had higher P concentrations, compared to other treatments and there were significant differences among the 0–10, 10–20, 20–30 cm depths (Figure 3c). In the third year, significant ($p < 0.05$) differences among treatments were shown in the 0–10 cm depth. Burning had the highest P concentrations in the 0–10 cm depth, while conventional tillage and the control treatments were second with comparable P concentrations (Figure 4c). Phosphorus concentrations in the 0–10 cm depth of the burnt plot increased from the second year to the third year. However, in the conventional tillage treatment P concentrations decreased from the second year to the third year (Figures 3c and 4c).

There were significant differences in exchangeable K concentrations among the treatments and the concentrations were highest in the burnt treatment in the 2nd year (Figure 3d). The same trend was also shown in the 3rd seasons, where K concentration in the burnt treatments was higher compared to the other treatments (Figure 4d). There were significant differences in K concentration among depths and the concentrations decreased with increasing depth (Figures 3d and 4d). For exchangeable Ca, the burnt and control treatments had significantly ($p < 0.05$) higher concentrations compared to other treatments in the 0–10 cm depth (Figures 2e and 4e). The Ca concentration decreased with increasing depth for both the second and third years. In the third year, the Ca concentrations remained high under burning and conventional tillage treatments (Figure 4e), and there were significant ($p < 0.05$) differences between burnt and tilled

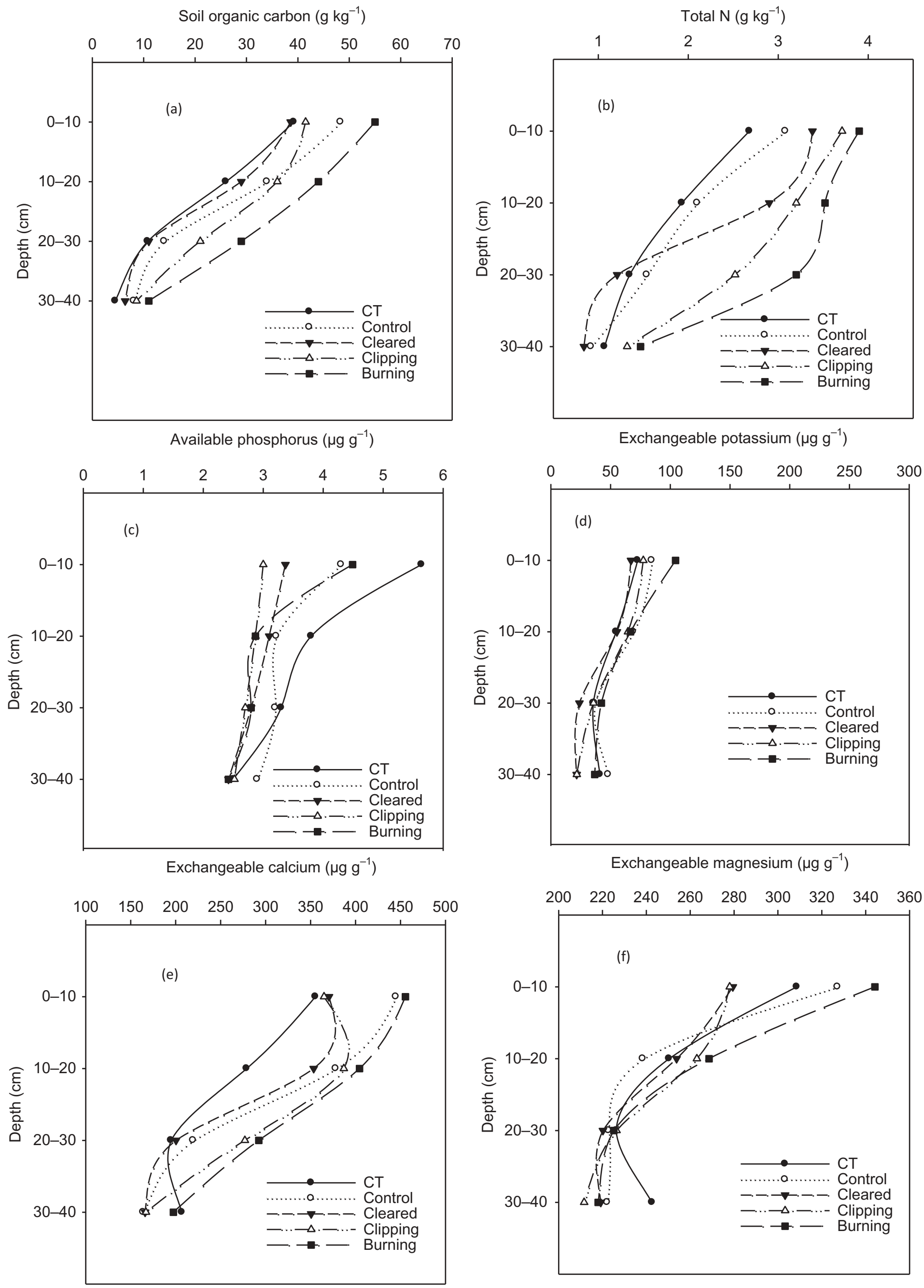

Figure 3. Concentrations of (a) SOC (b) total nitrogen (c) available phosphorous (d) exchangeable potassium (e) exchangeable calcium, (f) exchangeable magnesium at different depths under different management practices in 2012, 2 years after introduction of management practices. CT = conventional tillage.

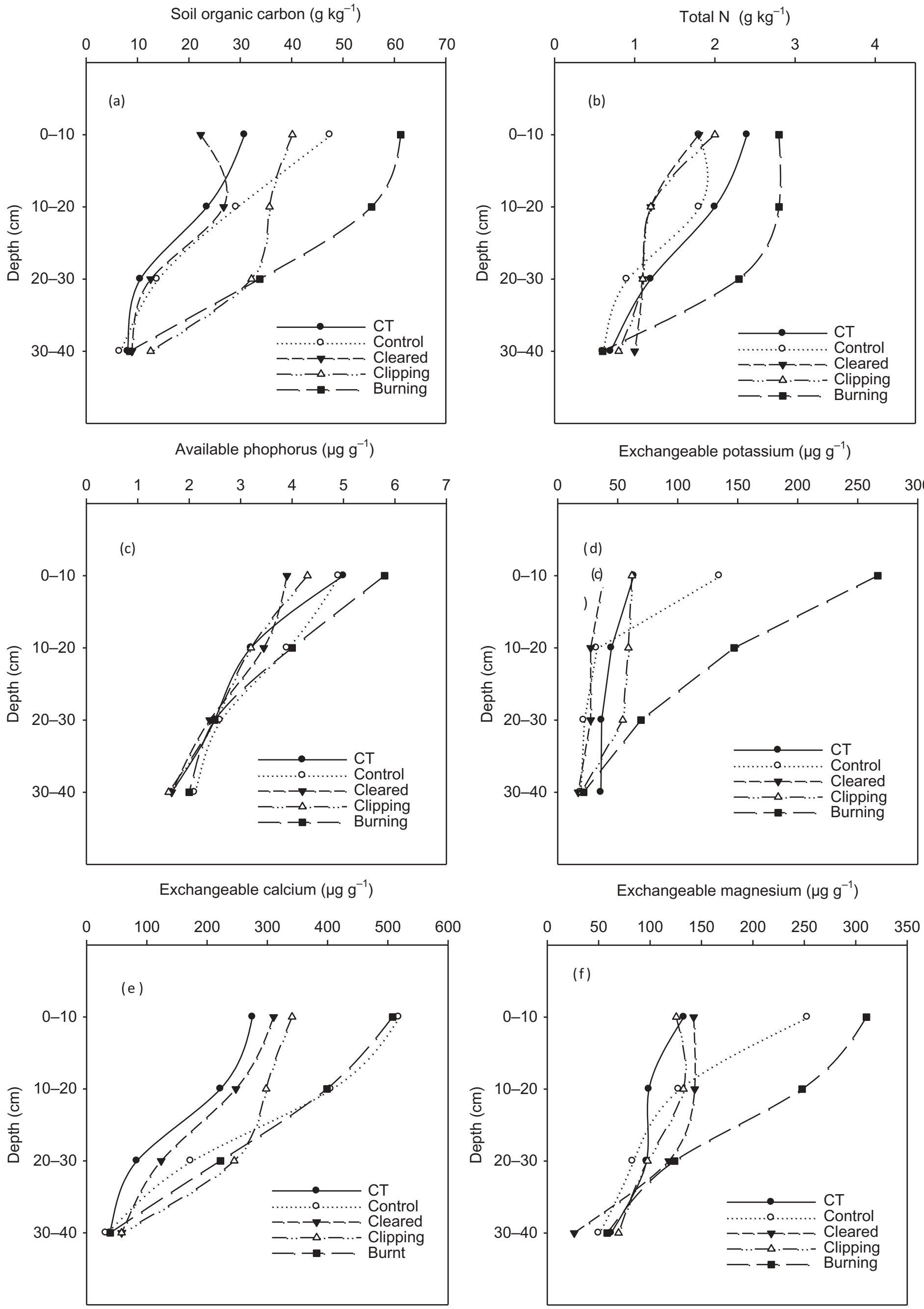

Figure 4. Concentrations of (a) SOC (b) total nitrogen (c) available phosphorous (d) exchangeable potassium (e) exchangeable calcium, (f) exchangeable magnesium at different depths under different management practices in 2013, 3 years after introduction of management practices. CT = conventional tillage.

treatments in the 0–10, 10–20 and 20–30 cm depths. In the second year, exchangeable Mg showed the same trend as Ca, except for the 0–10 cm depth, where there were significant differences among treatments. However, for Mg, there were no significant differences in concentrations for the 20 – 40 cm depth (Figure 3f). In the third season, Mg concentrations were significantly ($p < 0.05$) higher in the burnt treatment and were followed by the control (Figure 4f). There were significant differences between treatments in the 0–10 and 10–20 cm depths (Figure 4f).

Our results showed that total above-ground biomass production at the end of the rainy season, which ended in April, was highest in the undisturbed dambo (control) with an average biomass yield of 20.9 t ha^{-1} and this decreased significantly in plots which were burnt or which had biomass removed. The average biomass yields were 8.9, 4.9, 1.4 and 0.9 t ha^{-1} for burnt, clipped, cleared and ploughed treatments, respectively. Among the disturbed plots, the burnt plots had the highest biomass production compared to other treatments, while conventional tillage and clearing had the least biomass production. Although the disturbed treatments had more species diversity (Table 3), the overall biomass production decreased. Among the disturbed treatments, clearing had the highest species diversity and was dominated by annuals. Although the species diversity increased in the disturbed treatments, biomass additions did not increase as most short-lived annuals had low biomass production.

Discussions

In Chiota, the soils are mainly sandy and are derived from granitic parent material. Textural analysis showed similar results to the soil catenary sequences that were investigated in earlier studies in Chiota (Bell & Roberts 1991; Nyamadzawo et al. Forthcoming 2013a).

Table 3. Plant species composition in plots subjected to different annual disturbance regimes for 3 years.

Control	Conventional tillage	Clipping	Cleared	Burning
Conyla banariensis	*Sesbania sesban*	*Cyanodon dactylon*	*Kyllinga erecta*	*Senecio strictifolius*
Euphorbia spp. 2	*Kyllinga erecta*	*Paspalum urvillei*	*Senecio strictifolius*	*Cyanodon dactylon*
Paspalum urvillei	*Bulbostylis buchanami*	*Kyllinga erecta*	*Bulbostylis buchanami*	*Bulbostylis buchanami*
Senecio strictifolius	*Cyperus esculentus*	*Cyperus esculentus*	*Cyperus esculentus*	*Cyperus esculentus*
	Cyanodon dactylon	*Conyla banariensis*	*Cyanodon dactylon*	*Paspalum urvillei*
	Paspalum urvillei	*Richardia brasiliensis*	*Paspalum urvillei*	*Conyla banariensis*
	Unidentified species	*Eragrastis tennifolia*	*Euphorbia* spp.	*Richardia brasiliensis*
	Hibiscus spp.	*Satyrium trinerve*	unidentified species	unidentified species
			Hibiscus spp.	
			Commelina forskaolii	

The sand content increased with increasing depth, while the clay and silt contents decreased with depth, and this could be attributed to the loss of clay through flowing water as depth increased from the soil surface, as dambos are zones of water transmission. The dambo soils at the study site were acidic, and this can be attributed to the loss of bases through leaching, because of the sandy texture that has low base retention capacity, and this is a common trait in sandy dambo soils of Zimbabwe. The soil pH of the burnt treatments was not significantly different from other treatments, possibly because the soil sampling for the determination of soil properties, including pH, was done 6 months after burning. Burning was carried out in October (peak of dry season), while soil sampling was carried out in April (end the end of the dry season). Miao et al. (2010) reported immediate pulsing in water pH after fires in the Florida Everglades. In addition, the area of burnt plots was small relative to the size of the whole dambo garden where water movement was not restricted; and therefore, dilution effect from the rest of the dambo garden could have resulted in the lack of a significant increase in pH in the burnt plots.

Dambo cultivation, which is based on conventional tillage for land preparation, has been reported to result in a decline in SOC, and similar results were also reported by the Dambo Research Unit (1987). Studies on fertility of dambo soils by Grant (1995) also showed that continuous dambo cropping of maize resulted in a decline in SOC content. In Southern Africa, conventional tillage, mainly involving mouldboard conventional tillage using ox- or donkey-drawn plough, and digging, using hand hoes, often cause a decline in soil organic matter (Chuma & Hagmann 1995). In this study, the ploughed treatment lost more than a third of the SOC in the 0–30 cm depth in just 3 years. Cultivation exposes the SOC stored in the dambo to microbial oxidation, thus increasing SOC breakdown. In the ploughed treatments, there was an increase in the concentration of available P and this could be attributed to P mineralization during SOC decomposition. The SOC depletion is generally higher for plough-based systems of seedbed preparation and in subsistence farming systems (Lal 2007). Besides the cultivation of dambos, other management practices, e.g., clearing and clipping, also affected SOC and nutrient status of dambo gardens. Clearing resulted in a reduction in biomass and SOC addition to the soil, and soil nutrient contents that were similar to that of cultivated plots. Clearing, just like conventional tillage, removes all vegetation; as a result, it had low biomass and SOC addition to the soil.

Our results showed that SOC was highest in the burnt plots in the 0–30 cm depth compared to other treatments. Results consistent with our findings were also reported by Pardini et al. (2004), Zhao et al. (2012) and Adeyolanu et al. (2013). High SOC in burnt treatments can possibly be due to the fact that burning resulted in root die-back and higher root turnover. Czimczik et al. (2005) and Oluwole et al. (2008) observed that more frequent burning and greater fire severity led to the increase of SOC due to the increased surface biomass and underground carbon pool from dead roots. Zhao et al. (2012) reported that fire increased wetland SOC immediately after burning; however, the effect of fire diminished with time, because fires increased the microbial metabolism in the post-burning period, resulting in higher carbon losses from the ecosystem, compared to undisturbed ecosystem.

Adeyolanu et al. (2013) reported that burning resulted in an increase in the nutrient contents in Ibadan, Nigeria. This may suggest that burning is not only carried out to prepare land by farmers, but is also a practice to improve soil fertility status. Fire releases the nutrients (N, P, K, Ca and Mg) held in plant biomass and returns them to soil (Shah 2012). Burning of vegetation for soil fertility improvement has been used in traditional agricultural systems such as shifting cultivation and Chitemene system in Zimbabwe and

Zambia. During burning, all plant material that is not dry will die back, this will decompose and increase SOC and soil nutrient contents. Similar increases in soil nutrient contents, immediately after fire, were also reported by Monleon et al. (1997), who reported that the increase in mineral soil nitrogen returned to the pre-burning level in a few years. In addition, burning stimulates new plant growth and produces higher biomass during the rainy season as plants exploit the post-fire conditions of increased nutrient contents (Vasey et al. 2005). Though our results also showed that fire increased wetland soil SOC immediately after burning, the period it will take before a decline in SOC due to burning is recorded in dambos is currently unknown and this calls for long-term studies. Zhao et al. (2012) reported significantly higher SOC in burnt plots than in the unburnt during the second post-burning growing season, but the difference in SOC level between burnt and unburnt plots, became smaller, suggesting that this increase and benefits of burning may be short-lived.

Although burning temporally increases the soil fertility status, the cost to the environment is huge. Burning contributes considerably to the concentrations of greenhouse gases (GHGs), such as CO_2 and nitrous oxide (N_2O). The Intergovernmental Panel on Climate Change (IPCC) attributes 17.3% of total anthropogenic emissions to biomass burning, making it the second largest source of GHGs from human activities, after the burning of fossil fuel. Burning can cause significant N and C losses from seasonally dry ecosystems. During fires, soil N may be lost through volatization at low temperatures (120°C) (Hart et al. 2005), though some studies, e.g., White et al. (1973), reported that N volatization occurred at temperatures >200°C. In Zimbabwe, N_2O–N losses from burning were estimated to be 2.36 Gg year^{-1} (Chenje et al. 1998). Scholes and Andreae (2000) estimated annual emissions of 6.7 Gg for N_2O, 7.2 Tg for CO_2 and 0.008 Tg for methane (CH_4) from burning in Zimbabwe. The work by Chenje et al. (1998) and Scholes and Andreae (2000) also suggested that burning is the single largest contributor to atmospheric N_2O and CO_2 during the dry season in Zimbabwe and Southern Africa, respectively. In addition, fires can also cause losses of nutrients through ash, wind erosion and surface run-off (Whitlow 1985). One of the most important ecological effects of burning is the increased probability of further burning in subsequent years as dead vegetation fall to the ground (van Wilgen 2009). At the regional and local levels, fires lead to change in biomass stocks, and alter plant and animal species' functioning. Fires also damage the seed bank, seedlings and saplings, and this may hinder recovery of the original species. Fire typically results in some mortality of individual seeds, stems and plants (Nyamadzawo et al. 2013). During a fire, biomass can remain as incompletely burnt organic matter (charcoal), or be redeposited as organic matter-derived ash. The practice of burning dambos, grasslands and woodlands to prepare for ploughing or for soil fertility improvement should be strongly discouraged in order to reduce greenhouse gas emissions into the environment. Burning in agricultural land, whether from veld fires or intentional fires, is against the principle of good agricultural practice.

The N content in all the treatments were low, except for the burning treatment. In their virgin state, dambos were reported to be very deficient in N (Grant 1995), and this is common in most soils of the seasonally dry ecosystem of sub-Saharan Africa, which are light-textured and acidic (Nyamangara & Nyagumbo 2010). In cultivated dambos, N can be immobilized during decomposition of buried organic matter, and this further reduces N availability. In the cleared and clipping treatments, the N locked in the biomass was lost through biomass transfer. The low nutrient contents in dambos are consistent with previous studies (Bell et al. 1987; Bell & Roberts 1991; Grant 1995).

The concentration of nutrients was highest in the 0–10 cm depth, where there was the highest SOC. The nutrient concentrations decreased with increased depth, as did SOC. There was a good correlation between SOC and total N, and this suggested that most of the N was held in SOC. Similar results showing positive correlations between SOC and total nitrogen were reported by Post and Mann (1990), Knops and Tilman (2000). Though dambos are perceived to be more fertile compared to uplands, the rapid decline in SOC following cultivation, and the low nutrient contents in dambo soils suggested that there is a need to apply external sources of nutrients to sustain crop production in dambo gardens. In dambos where tillage is practiced, the use of organic manures may be a sustainable and a better-placed way of maintaining soil fertility, reducing the decline in SOC (Beare et al. 1994; Sainju et al. 2006) and reducing GHG emissions.

Besides causing changes in SOC and soil nutrient contents, dambo disturbances through conventional tillage, clearing, clipping and burning also changed plant species diversity through modifying abundance or vigour of competitive species (Tilman 1988). In dambos, disturbed areas may have significantly higher diversity of successor plants, as disturbance enhanced the abundance of annuals and short-lived annual species compared to perennials. Disturbances, e.g., through clipping may result in reduced shoot and root growth of the vegetation (Matheson et al. 2002), while Crosslé and Brock (2002) reported that in some species, there was reduced biomass and reproduction. In our study, clipping, conventional tillage and clearing resulted in reduced biomass production and increased species diversity. Burning increased species diversity and had the highest biomass productivity among the disturbed treatments. This was possibly because the species exploit the post-disturbance conditions of reduced thatch and unpalatable tall grasses, increased nutrient contents which gave way for fresh growth full of vigour (Vasey et al. 2005; Ansley et al. 2006); although the biomass editions were lower than those from undisturbed dambos. In addition, continuous burning may also lead to the dominance of less biomass producing, fire-resistant species. Though the species diversity increased, the total biomass production was reduced in burnt plots; this may suggest that SOC and subsequent reduction in soil fertility may occur in the long term as a result of reduced biomass additions. Beringer et al. (2007) reported net biome production of −2.0 t carbon ha^{-1} $year^{-1}$ in fire-prone savannahs of Northern Australia, with similar tropical conditions to those in Zimbabwe.

Conclusions

The cultivation of dambos resulted in reduced SOC, soil nutrient contents and reduced biomass production relative to the control. Dambo disturbances resulted in reduced SOC, nutrient contents, standing biomass productivity and a change in species diversity, thus reducing SOC sequestration potential of dambos. The magnitude of reduction of SOC, soil nutrient contents and biomass additions in the cleared treatment was comparable to the conventional tillage treatment. Clipping of grasses did not result in significant changes in SOC and N concentrations compared to the control. However, it resulted in reduced above-ground biomass production. In dambos, burning resulted in increased SOC and nutrient availability, as nutrients that are locked in the plant are released after burning. However, burning reduced biomass production, and in the long term, this may result in reduced SOC, and possible negative environmental effects, hence it should be discouraged. Dambo disturbance resulted in reduced biomass production and it resulted in a change in species composition, where annuals replaced perennials. Dambo disturbance practices reduced SOC, thereby reducing the functions of dambo as carbon sinks. Dambos continue to degrade at an alarming rate, and as the cultivation of wetlands intensifies, farmers are increasing the damage to the dambo ecosystem. Though the effects of dambo disturbance from clipping, clearing, burning and conventional tillage on soil carbon pool is significant, their long-term effects on wetland carbon remains uncertain, since this study was limited to a short period (3 years), thus there is a need for long-term studies. In Zimbabwe, and in the region at large, the expansion in dambo cultivation will result in reduced SOC and subsequent reduction in soil fertility. This may result in increased degradation of dambo soils. Therefore, it is recommended that sustainable management practices, such as conservation agriculture, use of organic amendments and mulch retention should be promoted as ways of maintaining soil fertility and reducing the decline in SOC in dambos.

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