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LAND-USE TYPE EFFECTS ON SOIL ORGANIC CARBON AND MICROBIAL PROPERTIES IN A SEMI-ARID REGION OF NORTHEAST BRAZIL

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ABSTRACT

Land-use change is one of the most important anthropogenic environmental change drivers affecting the biodiversity and functioning of ecosystems. However, there is limited knowledge of the consequences for soil processes in many regions around the globe. The Brazilian semi-arid ecosystem known as Caatinga has experienced the transformation from native forest into agricultural land, with heretofore unknown effects on soil processes and microbial properties. The aim of this study was to evaluate the impact of five land-use changes (to maize and cowpea cropland, grape orchard, and cut and grazed pasture) on total organic C (TOC) and total N (TN) stocks and soil microbial properties of Ultisol from Caatinga. Soil samples (0–10 and 10–20 cm depth) were collected during the wet and dry periods. Split–split plot analysis of variance was used to test the effects of land use, soil depth, season and the interaction between land-use and soil depth on soil microbial properties, TOC and TN stocks. Land-use effects were more pronounced in the top soil layer than in the lower layer, while the pattern was less consistent in soil microbial properties. Land conversion from native forest to cropland may cause C losses from the soil, but conversion to pastures may even increase the potential of soils to function as C sinks. Grazed pastures showed not only high C and N stocks but also the highest soil microbial biomass and lowest respiratory quotients, all indications for elevated soil C sequestration. Thus, grazed pastures may represent a land-use form with high ecosystem multifunctionality in Caatinga. Copyright © 2014 John Wiley & Sons, Ltd.

KEY WORDS: soil organic matter; microbial biomass; soil quality; pasture; Caatinga

INTRODUCTION

Brazilian semi-arid ecosystems cover an area of about 980·000 km^2, which is roughly 12% of the land surface of Brazil inhabited by approximately 23 million people (Menezes *et al*., 2012). Nowadays, this ecosystem, known as Caatinga, has been managed as cropland and pastures, and about 80% of the original area has experienced land-use change (Menezes *et al*., 2012).

The main land-use practice is slash and burn of native vegetation to introduce annual crops or pastures (Sousa *et al*., 2012), and the effects of land use have become a key issue for the scientific community concerned with global environmental change (Munoz-Rojas *et al*., 2013). Especially in the semi-arid tropics, changes in land cover associated with different land-use types are important agents of environmental change and degradation (Fracetto *et al*., 2012; Wick *et al*., 2000; Sá *et al*., 2013), which has led to a decline in soil quality through significant changes in their physical, chemical and biological properties in response to soil organic matter (SOM) reduction and erosion (Jordán *et al*., 2010; Barbera *et al*., 2012; Bruun *et al*., 2013). In addition, land-use change, mainly through conversion of natural vegetation to cropland and/or grazed pastures, may influence many ecological properties (Yu *et al*., 2013a), such as soil carbon dynamics and soil microbial properties (Ussiri & Lal, 2013).

Particularly soil microbial biomass (SMB) was found to be very sensitive to changes in agricultural practices (Araujo *et al*., 2010; Yu *et al*., 2013b; Santos *et al*., 2012) and has been shown to be strongly affected by land-use change in this region (Nunes *et al*., 2012). Also, SOM is often used as an indicator of alterations in the soil environment, such as caused by land-use change, because of the close association with some ecological functions such as microbial decomposition and nutrient mineralization.

As the native vegetation of Caatinga often is cut to introduce cropland and pastures, there is the need to explore how such land-use changes affect SOM dynamics and soil microbial properties. Although several studies have shown that changes in land-use types involve changes in total organic carbon (TOC) and total nitrogen (TN) stocks (Jarecki *et al*., 2005; Assis *et al*., 2010; Sousa *et al*., 2012; Albaladejo *et al*., 2013), considerable uncertainties still remain concerning the magnitude of these effects in Brazilian semi-arid soils.

According to Brunn *et al*. (2013), the response of soil properties to forest conversion depends on the specific land-use type the forest is converted into. Pastures have great potential as C sinks (Wilsey *et al*., 2002; Davidson *et al*., 2002; Lopes *et al*., 2010), whereas croplands often lose C and nutrients (Li *et al*., 2003; Smith & Fallow, 2005; Song *et al*., 2005). In addition, different management systems may have strong effects on soil microbial properties by inputs

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of organic residues (Santos *et al.*, 2012), and these factors influence strongly soil organic C dynamics and soil properties. Here, we tested for the first time in a comparable way the consequences of land-use change (five different land-use types) on soil abiotic and biotic properties in semi-arid ecosystems in Brazil.

We hypothesized that different land-use types alter the functional properties of soil microbial communities and soil C sequestration in semi-arid ecosystems in Brazil. We expected higher soil microbial functioning and C sequestration in pastures than in croplands, with differences being more pronounced in the upper 10 cm of the soil layer than deeper in the soil. However, we had no clear expectation if conversion from native vegetation to other land-use types would generally deteriorate soil processes.

MATERIALS AND METHODS

Study Area

The study area is located at São João do Piauí, Piauí State, Brazil (08°21′29″S and 42°14′48″W, 244 m). The native vegetation represents tropical dry forest 'Caatinga', characterized by xerophytes highly adapted to water stress conditions. The climate of the region is hot and semi-arid, classified as BShw according to Köppen. The mean annual rainfall and air temperature are 651·4 mm and 30·5 °C, respectively. The soil in the region under study is classified as Ultisol (FAO soil taxonomy); chemical and physical soil characteristics are given in Table I.

Five land-use types established in an area of 0·7 ha with homogenous soil conditions—cut pasture, cropland with maize, grazed pasture, grape orchard and cropland with cowpea—were evaluated. A native area [native forest (NF)] was included as reference of stable ecosystem. The main features and management history of each system are presented in Table II.

Soil Sampling and Analysis

Soil sampling was carried out twice in 2012, the first during the dry season and the second in the wet season. At each sampling period, each land-use type area was subdivided into four subplots (replicates). In each subplot, five subsamples were collected using a spade in two soil depths, 0–0·10 and 0·11–0·20 m, and pooled to form a composite sample. Additionally, volumetric metal rings (49·06 cm^3) were used to collect intact soil cores in order to determine soil bulk density in all depths, according to Embrapa (1997). The samples of the first campaign were used for soil chemical and physical characterization (Embrapa, 1997). The samples were passed through a 2-mm sieve, and a 300 g aliquot of each sample was separated, put into plastic bags and stored in a refrigerator at 4–8 °C for later determination of microbial biomass and activity. The remaining soil samples were air-dried and stored at room temperature prior to chemical analyses. Soil samples were ground and passed through a 0·21-mm sieve.

Total organic carbon content was measured by wet digestion using a mixture of potassium dichromate and sulfuric acid under heating (Yeomans & Bremner, 1988). TN was measured in the soil samples by the Kjeldhal method (Bremner & Mulvaney, 1982). TOC and TN stocks were calculated for each depth using the following expression: stock ($Mg\,ha^{-1}$) = TOC or TN contents ($g\,kg^{-1}$) × bulk density ($Mg\,m^{-3}$) × e (m), with e being the thickness of the layer.

Soil microbial biomass C (MBC) was determined according to Vance *et al.* (1987) with extraction of C from fumigated and unfumigated soils by K_2SO_4. An extraction efficiency coefficient of 0·38 was used to convert the difference in C between fumigated and unfumigated soil into MBC ($mg\,kg^{-1}$). Soil respiration was determined according to Alef & Nannipieri (1995). Soil samples (100 g) were placed in 300-mL glass containers closed with rubber stoppers, moistened at 60% of the maximum water-holding capacity and incubated for 7 days at 25 °C. Glass vials holding 10 mL of NaOH (0·5 $mol\,L^{-1}$), to trap the evolved CO_2–C, were placed in the aforementioned containers. On day 7 after the incubation, the glass vial was removed, and the CO_2 trapped in NaOH was then determined titrimetrically. The qCO_2 was calculated as the ratio of basal respiration to MBC. The qCO_2 results were expressed as g CO_2–C $day^{-1}\,g^{-1}$ MBC. Moreover, we calculated the ratio between MBC and TOC, which is a common measure for carbon availability (Santos *et al.*, 2012).

Statistical Analysis

Split–split plot analysis of variance (ANOVA) was used to test the effect of land-use type (native vegetation, cut pastures, grazed pastures, cropland with maize, cropland with cowpea and grape orchard), soil depth (0–0·10 and 0·10–0·20 m), season (dry and rainy season of 2012) and the interaction of land-use type × soil depth on soil microbial properties (MBC, MBC to TOC ratio, soil respiration and respiratory quotient) and SOM content (TOC and TN). Split–split-plot ANOVAs were performed because the same plots were re-sampled in the dry and rainy season, and because soil samples taken from one core in different depth were not independent from each other. Different soil depths were considered as 'subplots' and different seasons as 'sub-subplots' (Eisenhauer *et al.*, 2009; Scheiner & Gurevitch, 2001). As we had no repeated measurements (no true replicates) for season, we did not test interactions between season and land-use type and/or soil depth but included it as a main effect in the statistical analyses. Given that the effects of different seasons thus cannot be adequately tested, we will not discuss such time effects in detail. Nevertheless, including season allowed us to have repeated measures and more reliable measures of land-use effects. Least significant difference analysis was performed, and all differences reported in the text were tested and considered significant at $p < 0{\cdot}05$. All analyses were performed using SAS 9·3 (SAS Institute, Cary, NC).

RESULTS

Land-use type and soil layer had significant effects on TOC and TN stocks and microbial properties. We found several

Table I. Chemical and physical properties of the different soil layers (0–0·10 and 0·10–0·20 m) in different land-use types

Land-use type	pH_{H_2O}	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H + Al	SB	CEC	m
						($cmol_c\ dm^{-3}$)				(%)
0–0·10 m										
NF	6·3	0·3	0·3	2·3	0·4	0·03	2·28	3·3	5·4	0·9
CP	7·7	0·9	5·2	6·6	2·4	0·00	0·64	15·1	15·7	0·0
MC	7·3	0·6	2·2	4·7	1·6	0·00	1·29	9·1	10·4	0·0
GP	7·1	0·5	5·0	5·5	2·4	0·01	1·57	13·4	14·8	0·1
GO	7·3	0·4	0·8	1·7	0·7	0·00	1·15	3·6	4·7	0·0
CC	6·5	0·4	0·3	1·3	0·3	0·01	2·03	2·3	4·2	0·6
0·10–0·20 m										
NF	5·9	0·2	0·2	0·8	0·2	0·11	2·06	1·4	3·5	7·4
CP	7·8	0·5	5·9	7·9	3·0	0·00	0·85	17·3	18·1	0·0
MC	7·3	0·3	1·4	3·5	1·4	0·00	1·11	6·6	7·7	0·0
GP	7·1	0·3	3·6	4·5	1·9	0·00	1·34	10·2	11·6	0·1
GO	7·1	0·3	0·6	1·3	0·5	0·00	1·32	2·6	4·0	0·0
CC	6·1	0·2	0·3	0·8	0·1	0·09	2·23	1·4	3·6	6·4

	Clay	Fine sand	Coarse sand	Silt	Soil bulk density
			($g\ kg^{-1}$)		($g\ cm^{-3}$)
0–0·10 m					
NF	120	400	290	190	1·20
CP	220	250	100	430	1·28
MC	170	420	20	390	1·24
GP	270	210	80	440	1·21
GO	130	400	460	10	1·34
CC	100	820	50	30	1·33
0·10–0·20 m					
NF	120	370	310	200	1·22
CP	240	230	100	430	1·44
MC	150	560	10	280	1·36
GP	190	380	70	360	1·29
GO	150	370	450	30	1·36
CC	110	800	50	40	1·36

NF, native forest; CP, cut pasture; CM, cropland with maize; GP, grazed pasture; GO, grape orchard; CP, cropland with cowpea; SB, sum of base cations; CEC, cation exchange capacity; m, aluminium saturation.

significant interactions, meaning that land-use effects differed between soil layers (Table III). In general, land-use effects on TOC and TN contents and stocks were more pronounced in the top soil layer than in the bottom layer (Figure 1), whereas the pattern was less consistent for soil microbial properties (Figure 2).

Total organic carbon contents and stocks (overall means 0·9% and 12·11 $Mg\ ha^{-1}$, respectively) showed higher values in cut pasture than in grazed pasture (intermediate levels in grape orchard), with the latter having significantly higher TOC content and stock than maize with conventional tillage and cropland with cowpea (intermediate levels in native vegetation; Figure 1a, b). TOC stocks were significantly higher in the top than in the bottom soil layer (+70%; Table III). TN contents and stocks (overall means 0·06% and 1·11 $Mg\ ha^{-1}$, respectively) were highest in cut pasture and grazed pasture and lowest in cropland with cowpea and maize with conventional tillage, with intermediate values in grape orchard and native vegetation (Figure 1c, d). TN stocks were significantly higher in the top than in the bottom soil layer (+65%; Table III).

Soil MBC (overall mean 145·85 $mg\ kg^{-1}$) was significantly higher in the top soil layer than in the bottom layer (+96%; Table III). However, this difference was mainly due to very high soil MBC in grazed pasture (Figure 2a). Lowest soil MBC was found in cropland with cowpea. The ratio between soil MBC and TOC contents (overall mean 1·6%) was slightly but statistically higher in the bottom than in the top soil layer (+12%; Table III). The ratio was highest in grazed pasture in both soil layers and the bottom soil layer in cropland with cowpea and maize with conventional tillage (Figure 2b). Microbial respiration (overall mean 24·43 mg $CO_2\ kg\ day^{-1}$) was only significantly affected by land-use type with significantly higher values in cut pasture than in grazed pasture (all other land-use types had intermediate levels; Table III, Figure 2c). The respiratory quotient (overall mean 0·30 g CO_2–C $day^{-1}\ g^{-1}$ soil MBC) was significantly higher in the bottom than in the top soil layer (+47%; Table III). Further, the respiratory quotient was highest in cropland with cowpea and lowest in grazed pasture (Figure 2d).

Table II. Description and management history of the studied land-use types

Land–use type	Label	Description and management history
Native forest	NF	Brazilian Caatinga—preserved natural vegetation formed by xerophytic, woody and deciduous physiognomies with seasonal herbaceous layer (Sampaio, 1995). The main plant species found in the area (about 90% of total plant species) are *Commiphora leptophloeos* (Mart.) JB Gillett, *Diptychandra aurantiaca* (Mart.) Tul., *Caesalpinia bracteosa* Tul., *Piptadenia macrocarpa* Benth., *Xchinopsis brasiliensis* Engl. and *Mimosa hostilis* Benth. The net annual organic inputs (herbaceous biomass, leaves and branches) are 2·1 Mg ha^{-1}.
Cut pasture	CP	Deforestation was started in 1998 to give place to pasture with *Cenchrus ciliaris* L. In 2006, the implementation of the current irrigated pasture with *Pennisetum purpureum* Schumach was started. The soil was disk-harrowed, sub-soiled and levelled, and 2 Mg ha^{-1} of limestone was applied. The soil was fertilized annually with 150 kg ha^{-1} of P_2O_5, 45 kg ha^{-1} of N and 80 kg ha^{-1} of K_2O. The pasture is harvested three times per year, and for each harvest, 4·7 Mg ha^{-1} of goat manure is applied to the soil surface. The net annual organic inputs (weeding and herbaceous biomass) are 4·8 Mg ha $^{-1}$.
Cropland with maize	CM	In 1992, the maize (*Zea mays* L.) was introduced after slash and burn of native forest. Since then, annually maize under conventional tillage without fertilization is cultivated. The estimated mean yield was 1500 kg ha^{-1}. The crop residues are utilized for feed animals. At the end of maize cycle, soil is left fallow. The net annual organic inputs (weeding, fresh manure and herbaceous biomass) are 3·0 Mg ha^{-1}.
Grazed pasture	GP	In 1992, the pasture with the grasses *P. purpureum* Schumach, *Panicum maximum* Jacq. and *Andropogon gayanus* Kunth was introduced after slash and burn of native forest. Annually, only organic fertilization (4 Mg ha^{-1}) was utilized along with fresh residues from animals. The cycles of grazing and rest are alternated every 15 days. The net annual organic inputs (weeding, fresh manure and herbaceous biomass) are 1·9 Mg ha^{-1}.
Grape orchard	GO	Irrigated grape (*Vitis vinifera* L.) orchard cultivation was started in 2006 after removal of native forest. While implementing the orchard, the soil was disk-harrowed and levelled. The grapevine plants were planted in rows with a distance of 4 m between rows and 2 m between individual grapevines. The soil was fertilized during the planting with N (260 g $plant^{-1}$), P_2O_5 (120 g $plant^{-1}$) and K_2O (120 g $plant^{-1}$). Pests and diseases are chemically controlled. Chemical fertilization with N (160 kg ha^{-1}), P_2O_5 (110 kg ha^{-1}) and K_2O (160 kg ha^{-1}) and organic fertilization with goat manure (8 kg $plant^{-1}$ $cycle^{-1}$) are performed twice a year. The mean yield is 15 Mg ha^{-1} $cycle^{-1}$. The net annual organic inputs (pruning residues, herbaceous biomass and weeding) are 1·5 Mg ha^{-1}.
Cropland with cowpea	CC	Deforestation was started in 2006, and after removal of native forest, the area was cultivated with cowpea (*Vigna unguiculata* L.) under conventional tillage, without irrigation and chemical fertilization, one cycle per year and fallow. The mean yield is 0·2 Mg ha^{-1}. The net annual organic inputs (weeding and herbaceous biomass) are 0·5 Mg ha $^{-1}$.

DISCUSSION

Total Organic Carbon and Total Nitrogen Stocks

The results of this study suggest that land-use effects differed between soil layers being more pronounced in the upper 10 cm of the soil (Table III), which is in line with previous studies. In irrigated croplands of an Eutric Cambisol, cultivated with perennial banana and annual maize in Brazilian semi-arid regions, Assis *et al*. (2010) found that land-use change strongly affected TOC and TN stocks in the upper 15 cm of the soil compared with soil under native vegetation. Working in semi-arid areas of Spain including forestland, shrubland and cropland (cereals, fruit trees and citrus), Albaladejo *et al.* (2013) found that the change in TOC stocks was higher in the upper soil horizons and decreased in intensity with soil depth.

Some studies showed that the conversion from native forest to cropland in semi-arid areas reduces the surface TOC and TN stocks, mainly through reducing the quantity of plant inputs into the soil, increasing erosion rates, and accelerating the decomposition of SOM (Assis *et al*., 2010; Fracetto *et al*., 2012; Sousa *et al*., 2012; Albaladejo *et al*., 2013). On the other hand, the perennial land cover with higher and constant litter deposition in some croplands and pastures, compared with native forest, can contribute to the maintenance of soil moisture and lower soil surface temperatures, which can increase the topsoil stocks of TOC and TN (Stockmann *et al*., 2013). Specifically for Caatinga forest, there is no agreement on the effects of land-use changes on organic matter dynamics, with previous studies reporting both gains and losses in the stocks of soil C and N (Fracetto *et al*., 2012).

The largest part of TOC and TN stocks is stored in the topsoil (0–10 cm) in all land-use types evaluated (Figure 1). Compared with native forest, pastures (grazed pasture and cut pasture) increased the TOC and TN stocks probably because of the intrinsic characteristics of grasses associated with pasture management. The vegetation cover, the effective root depth of around 25 cm (Cunha *et al*., 2011) and the dense root system built by grasses contribute to

Table III. ANOVA table of *F*-values on the effect of area (native vegetation, pastures and cropland) on soil properties (TOC: total organic C; TOC stock, MBC: microbial biomass C, MBC : TOC; CO_2: soil respiration; qCO_2: microbial metabolic quotient; TN: total N; N stock) at different layers (top and bottom) and season (dry and rainy)

	df	TOC		TOC stock		MBC		MBC : TOC		CO_2		qCO_2		TN		TN stock	
		F	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*
Treatment	5	40·42	<0·001	24·43	<0·001	76·49	<0·001	17·29	<0·001	21·20	<0·001	15·18	<0·001	35·58	<0·001	24·41	<0·001
Plot	18	0·63	0·853	1·03	0·442	0·54	0·920	0·92	0·562	0·16	1·000	0·33	0·993	0·34	0·992	0·82	0·667
Layer	1	493·72	<0·001	313·99	<0·001	282·23	<0·001	4·70	0·044	3·41	0·082	8·54	0·009	308·09	<0·001	230·86	<0·001
Layer * Treatment	5	14·98	<0·001	9·49	<0·001	66·01	<0·001	7·86	<0·001	1·17	0·363	0·32	0·893	13·80	<0·001	7·76	<0·001
Subplot	18	0·19	0·999	0·18	0·999	0·23	0·999	0·43	0·973	0·22	1·000	0·33	0·993	0·16	1·000	0·18	1·000
Season	1	0·54	0·467	0·73	0·397	0·51	0·480	0·01	0·912	18·81	<0·001	9·50	0·003	0·08	0·783	0·19	0·664
Total error	47																

df, degrees of freedom.

increased water infiltration rates, reduced soil erosion and bulk density (Lopes *et al*., 2010), protecting the soil from losses of C and N stored in the top soil layer. Root turnover in grasslands is usually higher than in croplands because of regular removal of aboveground plant biomass by harvesting and grazing, and this can explain the higher TOC and TN stocks in grazed pasture and cut pasture than in the other land-use types. Rasse *et al*. (2005) reported that the root turnover and rhizodeposition are major determinants of soil organic C storage.

The TOC and TN stocks in grazed pasture were probably also influenced by the addition of livestock manure and the absence of soil tillage, which both provide favourable conditions for conversion of C and N in more stable forms. Despite soil tillage during implementation of the cut pasture system, the efficiency in accumulating TOC and TN stocks may have resulted from the combined use of mineral and organic fertilizers with irrigation that promotes higher mineralization of C and N, the increase of plant biomass yields and therefore greater organic matter inputs to the soil.

The lowest TOC and TN stocks in soils with the land-use types croplands with maize and cowpea can be explained by soil mismanagement: no use of organic inputs, no replacement of nutrients, no incorporation of crop residues, tillage and fallowing. In contrast to a previous study reporting reductions in TOC and TN contents in irrigated semi-arid fruit cultivation areas (Assis *et al*., 2010), grape orchard had higher TOC stocks in both soil layers and elevated TN stocks in the upper soil layer than native forest soils. Some features of the management of this land-use type may have contributed to these results, such as (i) the pergola trellising system, which helps to keep the soil moisture by shading; (ii) the herbaceous strata between the grapevines, which provide organic inputs into the soil and decrease soil erosion; and (iii) the use of goat manure as organic fertilizer and urea, which may contribute to the mineralization of N from organic residues and to the stabilization of soil organic carbon (Puget & Lal, 2005).

Soil Microbial Biomass

Soil microbial biomass is strongly influenced by the availability of organic matter, and this is also the main factor for the decreasing SMB with soil depth (Santos *et al*., 2012). Usually, in the topsoil, organic inputs to the soil (Santos *et al*., 2012) as well as high soil moisture and O_2 levels (Fierer *et al*., 2003) determine SMB. Especially in semi-arid ecosystems, the variability in soil moisture is much higher at the top soil than in lower soil layers (Wilkinson *et al*., 2002; Fierer *et al*., 2003), with pronounced effects on SMB.

In our study, SMB was strongly influenced by the pasture system, mainly in the topsoil. High SMB in the grazed pasture may be a direct response of three pasture plant species (*Pennisetum purpureum* Schumach, *Panicum maximum* Jacq. and *Andropogon gayanus* Kunth) and a high quantity of organic inputs (Table II). Different pasture plant species may have different effects on SMB as they differ in the quantity and quality of litter (Agbenin & Adeniyi, 2005).

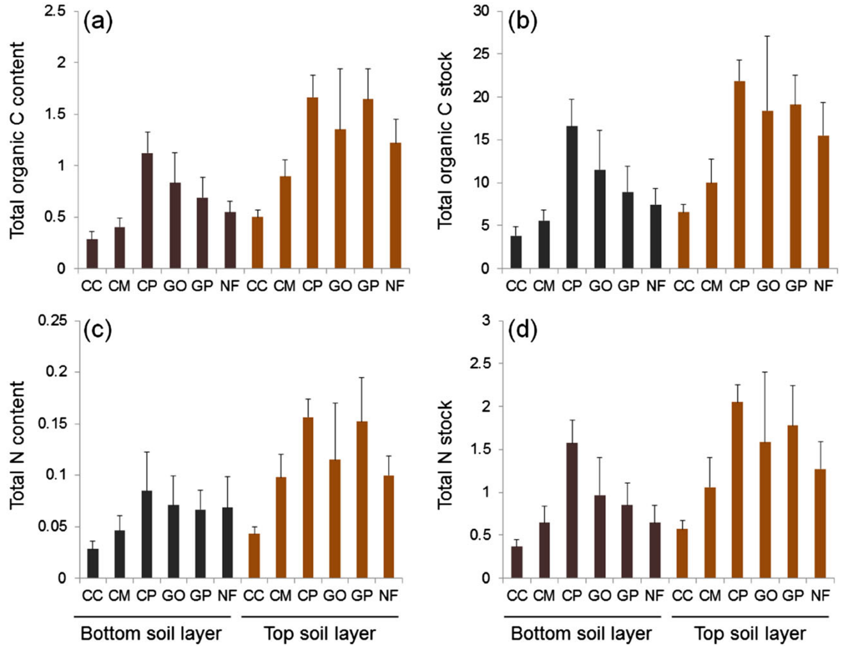

Figure 1. Effect of the land-use type (NF, native forest; CC, cut pasture; CM, cropland with maize; CP, cropland with cowpea; GO, grape orchard; GP, grazed pasture) and soil layer (top and bottom) on (a) total organic carbon content (%), (b) total nitrogen content (%), (c) total organic carbon stock ($Mg\,ha^{-1}$) and (d) total N stock ($Mg\,ha^{-1}$). This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

Such plant-specific effects may be particularly pronounced in the topsoil where more than 80% of herbaceous roots (here mostly grass roots) are found (Cunha *et al*., 2011). In accordance with this assumption, in a tropical dry soil, Lopes *et al*. (2010) found higher SMB in the topsoil in a pasture system with *P. maximum* as compared with systems dominated by *Leucaena leucocephala* (Lam.) de Wit. trees. According to Grayston *et al*. (1996), the quantity and quality of root exudation by plants influence SMB, and these exudations depend on plant species or functional group identity, such as grasses or legumes. Other studies using different crops that varied in amount, rate of decomposition and quality of residue inputs also showed significant effects on SMB (Ekenler & Tabatabai, 2002; Lopes *et al*., 2010).

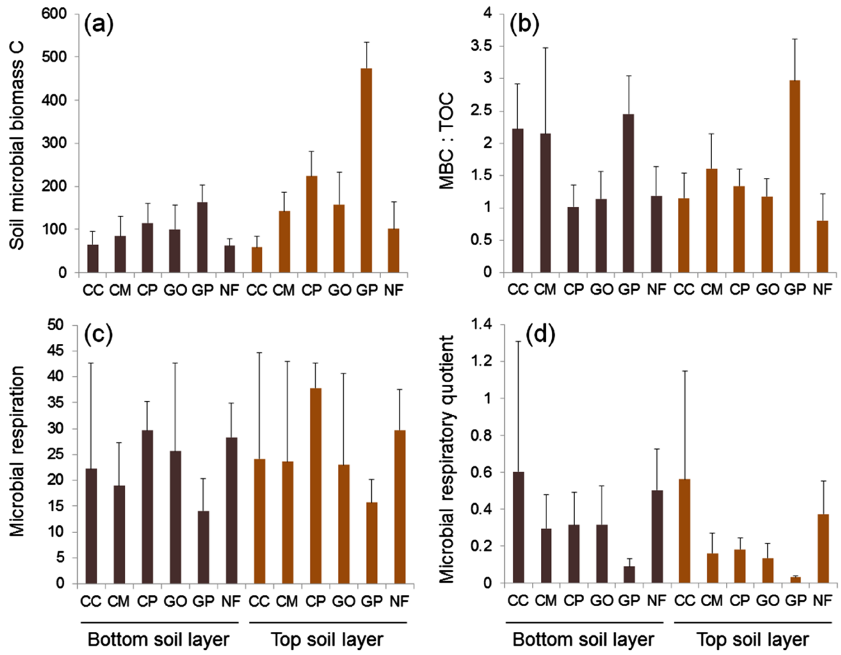

Figure 2. Effect of land-use type (NF, native forest; CC, cut pasture; CM, cropland with maize; CP, cropland with cowpea; GO, grape orchard; GP, grazed pasture) and soil layer (top and bottom) on (a) soil microbial biomass carbon ($\mu g\,g^{-1}$), (b) ratio between soil microbial biomass C and total organic carbon concentration (%), (c) microbial respiration [($mg\,CO_2\,g^{-1}\,day^{-1}$) day^{-1}] and (d) microbial respiratory quotient ($\mu g\ CO_2\ \mu g\ C_{mic}^{-1}\ dia^{-1}$). This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

The cropland systems showed lower inputs of C and N (Table II), which may have influenced SMB. These results are in agreement with those of Franzluebbers *et al*. (1995) who found higher soil MBC at 0–20-cm depth under pasture than under cropland. According to Franzluebbers *et al*. (1995), this was due to elevated inputs of organic C under grazed pasture, which led to greater storage of C in SMB. Thus, our results provide additional evidence that pastures have a high potential to sequester more C than cropland.

The microbial C to organic C ratio has been used as an indicator of changes in organic matter status in response to land use (Sparling, 1997). Usually, the values should range between 1% and 4% (Sparling, 1992); the values of soil MBC to organic C ratio in both the soil layers observed in the present study are within this range. This result is in accordance with Iyyemperumal *et al*. (2007) who found values between 1 and 2 in pastures. Also, the higher values found in pastures may be due to the higher soil MBC content observed in these systems, suggesting a large proportion of SOM being occupied by microbial biomass.

Soil respiration indicates biological activity and decomposition of organic residues (Santos *et al*., 2012). Our results showed low respiration in grazed pastures as compared with other systems. However, a high respiration rate might indicate either a disturbance of the soil or a high level of productivity in the ecosystem (Islan & Weil, 2000). The respiration rate per unit of microbial biomass or respiratory quotient (qCO_2) is a variable of more straightforward interpretation (Fernandes *et al*., 2005). qCO_2 reflects the efficiency of heterotrophic microorganisms to convert organic C into microbial biomass (Anderson & Domsch, 1990). Pastures system showed lower soil respiration, and the respiratory quotient indicates that pasture systems harbour more efficient soil microbial communities in terms of C use than cropland.

CONCLUSION

Our results highlight that land-use change can have strong effects on soil organic and microbial properties. Land conversion from Caatinga to cropland may cause C losses from the soil, but conversion to pastures may even increase the potential of soils to function as C sinks. Such effects were most apparent in the topsoil (0–10 cm), but are also relevant for deeper soil layers (10–20 cm), indicating that strategic land management can improve the function of soils considerably. Thus, important soil functions should be considered when assessing the multifunctionality of different land-use types.

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