Catena 143 (2016) 70–77

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Conversion of forest into irrigated pasture II. Changes in the physical properties of the soil☆

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ARTICLE INFO

Article history:
Received 4 June 2015
Received in revised form 17 March 2016
Accepted 17 March 2016
Available online xxxx

Keywords:
Soil use
Aggregates
Organic matter
Least limiting water range
S index

ABSTRACT

The replacement of natural vegetation (NV) by agricultural species may cause important changes in the ecosystem. Land use and management result in modifications of soil properties and functions, especially with the application of irrigation. The aim here therefore, was to assess the physical properties that are indicative of soil quality in an area under irrigated pasture (PAST), and to compare the results with those obtained in an area under natural vegetation. In order to identify changes in the soil, some physical attributes {aggregate stability, soil water retention curve, Dexter soil physical quality index (*S*), and least limiting water range} were determined, together with the total amount of lipids and glomalin, which can act as structure-stabilizing agents for different classes of aggregate. Rhizodeposition, a characteristic of grasses, and associated with the supply of plant biomass from the management practices used in PAST, may explain the differences in aggregate stability in the studied areas. The results showed that, despite the highest levels of lipids being found in PAST, it can be inferred that, due to the sandy texture and trampling by animals, there has been no effective structuring of the soil on the surface. In contrast to the trend observed for the lipid content of the soil, glomalin levels were greater in NV, and it was demonstrated that the glomalin content reacts sensitively to changes in land use. The least limiting water range (LLWR) is narrower under PAST when compared to NV, and reflects the loss of the physical quality of the soil due to the management of the pasture. Under such conditions therefore, plants may be susceptible to water stress when there is no irrigation. It can be concluded that the management of animals and pasture adopted in this study negatively affected the physical properties under evaluation, despite the better chemical and organic conditions of the soil.

1. Introduction

The growing human population has placed pressure on land resources, on changes in land use, and on impacts on soil quality (Materechera, 2014). The main agricultural frontiers for this expansion are those of tropical soils (Borlaug and Dowswell, 1998), due to their environmental conditions and characteristics favorable for agricultural activities (Tiritan et al., 2016). It is known, however, that the global conversion of tropical forests to agricultural land has declined over the past 10 years, but still remains at alarming rates in many countries (FAO, 2010; Jiménez et al., 2011).

The conversion of tropical forests into agricultural land is currently an ecological threat with serious implications for biodiversity and climate change (Fonte et al., 2014; Mutoko et al., 2015). Even that, there are important challenges for the assessment of the effects of conversion of land use due to the inherent variability of soils, the interactions between soil properties, climate and vegetation as well as the time required to detect small changes (Cook et al., 2014).

The replacement of natural vegetation by agricultural species may cause important changes in the physical and chemical properties of the soil, especially changes in soil organic matter (SOM), and in the distribution and stability of soil aggregates (Haghighi et al., 2010; Gajić et al., 2013). When natural areas are converted for use with pasture, it

Abbreviations: PAST, pasture; NV, natural vegetation; SOM, soil organic matter; *Bd*, bulk density; Bdc, critical bulk density; TOC, total organic carbon; TLE, total lipid extract; SWRC, soil water retention curve; LLWR, least limiting water range; S, slope of the soil water retention curve at its inflection point; PR, penetration resistance (MPa); θ, water content (cm^3 cm^{-3}); ψ, matric potential (MPa); θs, saturated water content (cm^3 cm^{-3}); θr, residual water content (cm^3 cm^{-3}) at 1.5 MPa of matric potential, α, m and n: model parameters; θ_{FC}, water content at field capacity; θ_{PWP}, water content at permanent wilting point; θ_{AFP}, water content at air-filled porosity of 10%; ρ_s, particle density; θ_{SPR}, water content at critical limit of soil penetration resistance for 2.0 MPa, *a*, *b*, *c*, *d*, *e* and *f*: model parameters.

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http://dx.doi.org/10.1016/j.catena.2016.03.016
0341-8162/

is common the use of *Brachiaria* spp. or other species, associated with the use of lime and fertilizer that ensures the optimization of biomass (Miles et al., 2004). Despite the initial investment, pastureland tends to degrade over time due to overgrazing or inappropriate land management (Jiménez and Lal, 2006).

This process of degradation of pastureland brings consequences, such as reduction in productivity and levels of organic matter, an increased susceptibility to erosion and depletion of the soil (de Oliveira et al., 2004; Martínez and Zinck, 2004; Fonte et al., 2014). Such conditions have economic implications and result in the trend for continued deforestation (Steinfield et al., 2006). In Brazil, for example, each year are invested USD 100–200 ha^{-1}, i.e. around 1 billion USD in total (FAO, 2006; Nesper et al., 2014) to the recovery of approximately 8 million hectares of degraded pasturelands (Jank et al., 2014).

However, the use of land for pasture can be beneficial, provided that the land is managed wisely. The addition of high quantities of organic soil amendments can increase the levels of soil organic matter (SOM), favoring the formation and stability of aggregates (Hurisso et al., 2013; Janzen, 2006; Tisdall and Oades, 1982). The growth of perennial grasses has been shown to enhance aggregate formation due to the production of polysaccharides and phenolics in the rhizosphere of the pasture (Milne and Haynes, 2004; Haynes and Beare, 1997; Tisdall and Oades, 1982). Additionally, the fungal hyphae associated with the fine roots of the grass physically enmesh fine soil particles into aggregates (Nesper et al., 2014; Milne and Haynes, 2004; Haynes and Beare, 1997; Tisdall and Oades, 1982).

Soil structure is the attribute most frequently evaluated when determining soil quality under different land uses and tillage practices (Moncada et al., 2014). Agricultural activities frequently lead to the degradation of the soil structure and consequently to changes in various hydraulic properties of the soil (Kodesova et al., 2011). Attributes such as pore size distribution, bulk density, aggregation and aggregate stability are important physical properties of soil, which to a great extent can be influenced by degradation of the land due to cultivation (Celik, 2005). Deterioration of the soil structure is perceived as a form of physical degradation of the soil (Pranagal and Podstawka-Chmielewska, 2012). These properties can be used as indicators of the physical quality of the soil (Reynolds et al., 2009).

There are several reports of the changes in soil properties, with physical soil properties having received little attention. This is perhaps due to the difficulties inherent in taking physical measurements of the soil (Papadopoulos et al., 2014). The nature and magnitude of such changes may be correlated with the duration and intensity of the agropastoral management practices adopted after conversion (Zucca et al., 2010). Long-term management systems, that may combine intensive practices such as irrigation or using land for pasture, would more efficiently express the changes in soil properties.

Table 1
Selected physical properties, pH of the soil and root density, under native vegetation (NV) and pasture (PAST) for a Typic Hapludult in Fortaleza, Brazil.

Depth (cm)	Sand	Silt	Clay	pH H_2O	Root density	TOC
	$g\ kg^{-1}$				$kg\ m^{-3}$	$g\ kg^{-1}$
NV						
0–10	915.23	65.13	20.13	6.24	0.97	26.92
10–20	895.35	73.24	32.05	6.35	0.56	11.04
20–40	872.20	82.31	46.09	6.33	0.27	7.65
40–60	801.29	91.15	108.36	6.22	0.08	7.78
60–80	765.47	112.22	123.45	6.44	0.06	2.02
PAST						
0–10	914.04	54.02	32.13	6.62	1.62	37.73
10–20	905.18	59.11	36.21	6.83	0.35	11.67
20–40	897.04	61.21	42.32	6.43	0.09	5.48
40–60	843.41	68.32	89.05	6.72	0.06	3.17
60–80	828.32	77.11	95.21	6.53	0.03	3.83

In this context, a large number of physical properties were chosen, in order to investigate the effects of converting forest to irrigated pasture for 10 years and to identify changes in the physical properties of the soil, by exploring the following issues: (a) Quantify the change of soil physical properties after land use, and (b) Determine which soil physical parameters can better represent the alterations caused by the use of soil.

The results may help select management practices that are best suited to areas where the vegetation and use of soil are similar to the area where the study was carried out, and select the physical properties of the soil, which may better represent the alterations resulting from soil usage.

2. Materials and methods

2.1. Description of the experimental area

The study was carried out at the experimental unit of the Agricultural Science Center of the Federal University of Ceará (3°44′32″ S, 38°34′39″ W, at an altitude of 19.5 m above sea level). The climate in the region is tropical wet, very hot, with most rainfall occurring in the summer and autumn (classified as Aw in the Köppen system). The mean annual rainfall, potential evapotranspiration and relative humidity are 1600 mm, 3215 mm and 62% respectively, and the mean annual temperature varies from 23 to 29 °C.

The soil in the area was classified as Typic Hapludult (Soil Survey Staff, 2010). A composite soil sample from each area and soil depth was selected for the chemical and physical characterization; results are presented in Table 1, together with root density.

The area used in the present study has been under agricultural management since 1982, mainly being used as pasture (PAST), except for the first six years, when it was cultivated with prickly pear. Since 1988, the area has been left fallow and is covered by the following spontaneous grasses: elephant grass (*Pennisetum purpureum*), brachiaria grass (*Brachiaria decumbens*) and guinea grass (*Panicum maximum*). In 1998, the area was renovated (mowed and harrowed), limed (at 1 t ha^{-1}) and again occupied spontaneously by Brachiaria grass (*Brachiaria decumbens*). This is the situation today.

A conventional sprinkler irrigation system was installed in 2000, when the area was divided into eight plots (49 m × 27 m). Irrigation was used for 12 h, every four days (at a flow rate of 666.5 L h^{-1} and average precipitation for each sprinkler of 3.80 mm h^{-1}). The water was classified as being of medium salinity and low sodium, according to the United States Salinity Laboratory (Richards, 1954).

Since 2000, four plots were kept under rotational grazing with sheep of an undefined breed. The herd consisted of approximately 62 breeder sheep, varying depending on the grassland biomass production and maintaining grassland use efficiency by 50%. Chemical fertilization was applied once a year as top dressing (Cantarutti et al., 1999) at 30 kg K_2O ha^{-1}, 80 kg P_2O_5 ha^{-1} and 600 kg N ha^{-1}, and organic fertilization of approximately 4 t manure ha^{-1} y^{-1}. Average production of dry forage biomass in the plots at the time the data was collected was 5.9 t ha^{-1}. The management in the area can be characterized as intensive grazing with rotational stocking, and irrigation in the dry season.

Another area, under natural vegetation (NV) and located near PAST, was selected and, having been exposed to little or no anthropogenic influence, was used as a reference area of the natural conditions. The terrain and class of soil in NV were similar to those seen in PAST, and the vegetation found in the area includes species of different strata: tree, herbaceous and shrub, with such evergreen species as *Auxemma oncocalyx*, *Guazuma ulmifolia*, *Cnidoscolus phyllacanthus* and *Croton sincorensis*, and deciduous species including *Ipomoea asarifolia* and *Arachis pintoi*.