Geoderma 167-168 (2011) 61–70

Contents lists available at SciVerse ScienceDirect

Geoderma

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

Soil physical quality of Luvisols under agroforestry, natural vegetation and conventional crop management systems in the Brazilian semi-arid region

G.L. Silva [a], H.V. Lima [b], M.M. Campanha [c], R.J. Gilkes [d], T.S. Oliveira [a,*]

[a] Universidade Federal do Ceará, Campus do PICI, Bloco 807, 60455-760, Fortaleza, CE, Brazil
[b] Universidade Federal Rural do Amazonas, 66077-530, Belém, PA, Brazil
[c] Centro Nacional de Pesquisa em Caprinos, EMBRAPA, 62011-970 Sobral, Ceará, Brazil
[d] School of Earth and Environment, The University of Western Australia, CRAWLEY WA 6009, Australia

ARTICLE INFO

Article history:
Received 20 July 2010
Received in revised form 3 September 2011
Accepted 16 September 2011
Available online 2 November 2011

Keywords:
Agroecology
Soil structure
S-value
Least limiting water range
Water retention
Soil penetration resistance

ABSTRACT

The imposition of agricultural systems changes the natural equilibrium of the soil to an extent that it becomes dependant on management practices and soil resilience. Agroforestry systems (AFs) mimic characteristics of natural ecosystems such as multistrata canopy and deep rooting and may minimize the consequences of these changes by providing soil protection and maintenance of conditions similar to those under natural vegetation. This study evaluates the physical properties of a Luvisol at a site where since 1997 alternative agroforestry systems (AFs) (agrosilvipasture—AGP and silvipasture—SILV), conventional crop management (CCM) and natural vegetation (NV) have been maintained. Undisturbed soil cores were collected in 2005 and submitted to a range of matric suction for which soil bulk density (BD), soil penetration resistance (Q) and soil water content (θ) were determined. Water retention and penetration resistance were used to determine the least limiting water range (LLWR) and the slope of the soil water retention curve at its inflection point (S-value). Particle size, total organic carbon (TOC) and particle density were determined using the disturbed soil samples. Water retention and porosity followed the sequence NV > SILV > CCM > AGP. The AFs studied (AGP and SILV) improved or maintained soil physical quality when compared to NV with no significant differences between the S-values of 0.044, 0.042 and 0.050, respectively. However, the S-value of 0.035 for CCM indicates that this management was unable to maintain soil physical quality on the same levels as AFs and NV. The decrease of LLWR with BD occurred for all treatments, and the BD at a maximum effect (LLWR = 0) which is called the critical BD (BD_c), was, respectively, 1.69, 1.62, 1.56 and 1.56 Mg m^{-3} for AGP, SILV, NV and CCM. The larger values of LLWR for AFs (AGP and SILV) are similar to the value for NV, with associated superior aeration, matric suction and reduced resistance to penetration by roots. Indices such as LLWR and S-value were suitably sensitive and could be used in future research, but it is important to identify other potential indices for these situations that can show how quickly changes in soil quality may occur.

1. Introduction

Semi-arid regions have highly fragile ecosystems that are characterized by low soil fertility, high organic matter decomposition rates, high soil erosion, limited water availability and sporadic precipitation that greatly limit agricultural production (Austin and Vivanco, 2006; Breman and Kessler, 1997; Solomon et al., 2000). In Brazil, the semi-arid region is mainly located in the northeast, covering approximately 800.000 km^2 (11% of the country's territory), with a typical Caatinga (dryland) vegetation, a seasonal xerophilous thorn woodland/shrubland, which prevails in the semi-arid lowlands on an extensive regional crystalline basement complex (Sampaio, 1995). The Brazilian semi-arid region is listed among the most densely populated semi-arid territories in the world (Ab'Saber, 1999; Figueirôa et al., 2006). The typical agricultural systems in this area are characterized by high grazing density, uncontrolled fire use, indiscriminate tree cutting (wood and charcoal

Abbreviations: AFs, agroforestry systems; AGP, agrosilvipasture; SILV, silvipasture; NV, natural vegetation; CCM, conventional crop management; BD, bulk density; TOC, total organic carbon; SWRC, soil water retention curve; LLWR, least limiting water range; S, the slope of the soil water retention curve at its inflection point; Q, soil penetration resistance (MPa); θ, water content (m^3 m^{-3}); ψ, matric suction (MPa); θ_s, saturated water content (m^3 m^{-3}); θ_r, residual water content (m^3 m^{-3}) at 1.5 MPa of matric suction; α, m and n, van Genuchten 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_Q, water content at critical limit of soil penetration resistance for 3.5 MPa; a, b and c, soil penetration resistance model parameters; d,e and f, soil water retention curve model parameters.

* Corresponding author. Tel.: +55 85 33669693; fax: +55 85 33669690.
E-mail address: teo@ufc.br (T.S. Oliveira).

0016-7061/$ – see front matter
doi:10.1016/j.geoderma.2011.09.009

production for industrial and domestic uses) and a fallow time that is typically shorter than is required to substantially enhance soil properties. Consequently, plant coverage of soil is reduced and soil degradation occurs (Bird et al., 2007; Lucena et al., 2007; Sampaio et al., 1993).

Sustainable and productive agricultural systems need to be developed for this environment. Agroforestry systems, which consist of growing trees, crops and sometimes animals in an interacting combination, create land-use systems that are structurally and functionally more complex with greater efficiencies of resource capture and utilization (nutrients, light, and water) than traditional land management. The greater structural diversity includes tighter nutrient cycles, soil conservation, carbon storage, biodiversity conservation, and enhancement of water quality (Nair et al., 2008). Soil quality under agroforestry systems is more similar to that under natural vegetation than under traditional or intensive agricultural systems (Maia et al., 2006; 2007; 2008). The classical definition of soil quality is the capacity of a specific soil type to function within natural or managed ecosystem boundaries, sustain plant and animal productivity, maintain or enhance the quality of water and air, and support human health and housing (Doran and Parkin, 1994). Soil quality under agroforestry systems in semi-arid climates needs further study in relation to these criteria.

Studies involving agricultural systems and soil quality mostly report chemical and biological soil properties, whereas the physical properties have received relatively little attention. Although, most soil properties are interdependent it is important to determine all properties to provide a better understanding of soil conditions. Physical properties of soils require careful monitoring as they strongly affect water and nutrient absorption and thus optimum plant development (Dexter, 2004). The least limiting water range (LLWR) and *S*-value (slope) are two quantities that evaluate soil physical quality (da Silva et al., 1994; Dexter, 2004). They provide measures of the influence of management systems soil structure, porosity, bulk density, penetration resistance and water retention. The LLWR considers the range of soil water content within which plant growth is least limited by water potential, aeration and mechanical impedance. The critical limits are associated with field capacity (−0.01 MPa), wilting point (−1.5 MPa), aeration ($0.10\ m^3\ m^{-3} = 10\%$) and penetration resistance (3.5 MPa). *S*-value is a soil physical parameter, equal to the slope of the soil water retention curve at its inflection point when this curve is drawn as gravimetric water content vs. natural logarithm of matric suction. Several studies have considered the use of LLWR and *S*-values for the evaluation of soil physical quality and have confirmed their potential for comparative studies of soil management (Beutler et al., 2004, 2005; da Silva and Kay, 1996, 1997, 2004; da Silva et al., 1994; Lapen et al., 2004; Leão et al., 2005; Leão et al., 2006; Tormena et al., 1999; Zou et al., 2000). These indices have not been used to evaluate agroforestry systems on sites with a high natural spatial variability in soil properties as is the case for Luvisols.

The evaluation of these soil parameters for alternative agricultural systems in semi-arid conditions has a particular importance in relation to the availability of soil water for crop production. In this context, the objective of this study was to evaluate soil physical quality for some agroforestry systems proposed for the Brazilian semi-arid region and to compare values for soils under conventional crop management and natural vegetation.

2. Materials and methods

2.1. Experimental area characterization

The experimental area is located on the Crioula Farm, part of the National Caprine Research Center of EMBRAPA, Sobral, Ceará, Brazil. The site is in the semi-arid location of Ceará at 3° 41′ S and 40° 20′ W, with an altitude of 70 m above sea level and a predominant slope between 3 and 20%. The average annual temperature is 27 º C and the average annual rainfall is 822 mm, concentrated mainly in the months of February to May (IPECE, 2005). The soils of the area are typical Ortic Chromic Luvisol and typical Ortic Hypochromic Luvisol (Aguiar et al., 2010). The predominant vegetation in the area is the Caatinga, consisting mostly of deciduous species, which lose their leaves during the dry season that occurs from June to January (Araújo and Tabarelli, 2002). Since 1997, a long term experiment has been conducted to evaluate agroforestry alternatives to the traditional and conventional agricultural systems of the region (Table 1).

All treatments studied (without replications) are physically adjacent to each other on the farm being separated by fences, except for CCM which is located 200 m away from the other areas. Quantification of inputs and outputs for all areas can be found in Maia et al. (2007)

Table 1
Description of experimental agroforestry systems, conventional crop and natural vegetation areas located at Sobral — CE, Brazil.

Experimental areas (area)	Cropping system	Dominant tree families	Historic and soil management	Net annual input ($Mg\ ha^{-1}$)[a]
Agrosilvipature (AGP) (1.6 ha)	Alley with *Leucaena sp* spaced every 3 m, maize (*Zea mays* L.) cultivated between the rows (wet season) and grazing by 20 ewes (*Ovis aries*) for 1 h day^{-1} (dry season)	*Borragonaceae*, *Caesalpinaceae* and others with limited abundance	Deforestation to get a total of 200 trees ha^{-1} (22% of soil cover), wood manure allocated to perpendicular to the slope to form rows. Soil preparation using manual hoe (first 3 years) and animal traction hoe for weed control. Organic manure	4.1[b]
Silvipasture (SILV) (4.8 ha)	Grazing by 20 ewes (dry and wet season)	*Borragonaceae*, *Mimosoidea* and others with limited abundance	Deforestation to get a total of 260 trees ha^{-1} (38% of soil cover), manure allocated perpendicular to the slope to form rows. No soil preparation and organic or chemical fertilization	4.5[c]
Conventional crop management (CCM) (1.2 ha)	Annual crops of maize (*Zea mays* L.) and beans (*Vigna unguilata* L. Walp) between 1998 and 2002 and after fallow	–	Total deforestation and annual burning of residues on surface before soil preparation and manual hoe for soil preparation. No organic or chemical fertilization	1.3[d]
Natural vegetation (NV) (3.1 ha)	Native vegetation known as ‘Caatinga’ that consists of small and thorny trees that shed their leaves seasonally	*Borragonacea*, *Euforbiaceae*, *Caesalpinaceae*, *Papilionaceae*, *Combretaceae*, *Borragonaceae*, *Mimosoidea* and others with limited abundance	Trees were cut in 1981 before and eventual annual grazing of herbaceous plants in severe dry season	3.7[e]

[a] Maia et al. (2007).
[b] Organic inputs = wood and leaves from deforestation at the beginning of the experiment + tree leaves + pruning from *Leucaena sp* and native trees + manure + weeding. Organic outputs = crop residues (grain and straw) + hay of *Leucaena sp* + grazing.
[c] Organic inputs = wood and leaves from deforestation at the beginning of the experiment + tree leaves + manure. Organic outputs = grazing.
[d] Organic inputs = weeding + crop residues. Organic outputs: harvest of maize (*Zea mays* L.).
[e] Organic inputs = leaves and herbaceous biomass. Organic outputs = grazing.