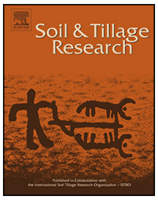
Soil & Tillage Research 137 (2014) 23–32

Contents lists available at ScienceDirect

Soil & Tillage Research

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



# Changes in soil pore network in response to twenty-three years of irrigation in a tropical semiarid pasture from northeast Brazil

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ARTICLE INFO

*Article history:*
Received 23 July 2013
Received in revised form 4 November 2013
Accepted 7 November 2013

*Keywords:*
Wetting and drying cycles
Soil air permeability
Pore continuity index

ABSTRACT

Irrigation is a technique in agri-, vini- and horticulture which consists in the controlled supply of water and which has been used for many years in order to ensure agricultural productivity in many regions of the world. In regions where this water application technique is used there is the possibility of changes in soil properties; amongst others, soil structure, a physical attribute that is related to several other soil attributes such as density, porosity and aggregate stability. Soil structure is also greatly affected by wetting and drying cycles, which are provided by irrigation in these regions. This study aims at evaluating changes in the physical attributes of a soil caused by 23 years of irrigation. The study area is located on the Apodi Plateau, Ceará, Brazil. Two areas were evaluated, one irrigated by a central-pivot sprinkler system and a non-irrigated control. For the study, eight disturbed soil samples were collected in each area, in the layers of 0–20, 20–40 and 40–60 cm, and four undisturbed soil samples, using cylinders of 5 cm × 5 cm, in the layers of 0–20 cm and 20–40 cm. The analyzed physical attributes were: particle density, soil bulk density, particle size distribution, total porosity, macroporosity (pores with diameter $\geq$ 50 $\mu$m, applying matric potential of $-6$ kPa), microporosity (pores with diameter $<$50 $\mu$m, total porosity minus macroporosity), soil air permeability, soil resistance to penetration, aggregate stability and pore continuity indices. The results indicated that irrigation contributed to changes in soil physical attributes directly related to soil structure. Also, the consequent wetting and drying cycles were sufficient to improve aggregate stability; however, these cycles, combined with processes of translocation and compaction, have increased microporosity, causing the formation of less continuous and more tortuous pores and lower soil air permeability.

## 1. Introduction

The soil is a multiphase and complex system which contains sand, silt and clay mineral particles in its solid phase, which are usually associated, forming structural sub-units of different sizes and properties called aggregates or peds (Soil Survey Staff, 1993). In a broader sense, aggregate size, stability as well as the amount, distribution and size of pore space between and inside the aggregates characterize the soil structure (Six et al., 2004). Thereby, soil structure plays a fundamental role for different soil processes, such as water movement, heat transfer and aeration. From a pedological perspective, soil aggregates are among the most stable products that the pedogenetic processes can create within a soil horizon (Schoeneberger et al., 2002) and that they, therefore, are one of the most significant morphological features for both soil genesis and classification.

However, soil structure can be altered by many different factors, often as a response to anthropogenic actions associated to land use. In this context, intense irrigation of soils in arid and semiarid regions stands out as one of the most prominent anthropogenic changes in these climatic regions. The adoption of irrigation in semiarid regions may cause changes in soil moisture and alter many soil properties (i.e., soil porosity, structure, density and infiltration) and processes (i.e. argiluviation and dissolution of carbonate features), contributing to significant soil changes (Swanepoel et al., 2013). Moreover, this technique causes changes in chemical attributes. According to Wiethölted (1997), the addition of water via irrigation accelerates the soil acidification process, through the leaching of base cation ($Ca^{2+}$, $Mg^{2+}$, $K^{+}$ and $Na^{+}$). Ongley (2000) claims that with the expansion of irrigated areas, the problems of natural resource degradation also increase, especially due to the increase in soil salinity and sodicity.

Thus, the change of the natural hydrological cycle caused by irrigation modifies the soil moisture regime and, therefore, may

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0167-1987/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.still.2013.11.004

alter and/or intensify processes such as leaching, translocation of ions or colloids and addition of soluble salts. Similarly, soil structure, as well as soil properties related to it, may be influenced by a modified soil moisture regime which causes soil particles to be rearranged, especially during drying (Bullinger-Weber et al., 2007). Previous studies (Sartori et al., 1985; Pagliai et al., 1987) indicate that wetting and drying cycles may cause changes in the soil pore system and induce soil aggregation.

The formation of aggregates through wetting and drying cycles occurs because the dehydration produces a contraction in the soil mass and a consequent cementation of clay particles. When dry soil clods are moistened, two phenomena arise: (1) fast water adsorption, which causes an uneven swelling, producing clod breaking along the fracture plane, and (2) capillary water sorption, which causes compression of the trapped air and, eventually, when the pressure is higher than the cohesion force of the particles, the clod breaks down (Amaro Filho et al., 2008). During wetting, clay particles tend to disperse, and then form bridges and coatings during drying (Attou and Bruand, 1998). That leads to a closer contact between clay particles and increase in aggregation (Singer et al., 1992). Wetting and drying cycles are important for aggregation of soils from arid, semiarid and subhumid regions (Dalal and Bridge, 1996).

Moreover, wetting and drying cycles have been shown to affect soil resistance to penetration, soil cohesion, aggregate size and its mechanical stability (Rajaram and Erbach, 1999). These cycles may even cause aggregates formation in unstructured soils (Telfair et al., 1957; Newman and Thomasson, 1979), promoting reorientation of the particles.

We hypothesize that 23 years of irrigation of calcareous soils from a semiarid region in northeast Brazil cause changes in soil physical attributes directly related to soil structure. The objective was to verify to what extent irrigation and its effects on wetting and drying intensity can contribute to changes in soil physical attributes.

## 2. Materials and methods

### 2.1. Study area and sampling

The study area is located in the irrigated perimeter in the Apodi Plateau, Limoeiro do Norte, Ceará state, Brazil. According to the Köppen classification the climate type is BSw'h', hot and semiarid (Brasil, 1973). The annual average temperature is 28.5 °C, with a minimum of 22 °C and a maximum of 35 °C. The mean relative air humidity is 62% while evapotranspiration reaches mean annual values of 3215 mm (Dnocs, 2012).

Two sites, which are about 40 m apart, were studied: one where grass (Tifton grass; *Cynodon niemfluesis* L.) is grown under irrigation (for cattle pasture) by a central-pivot system (05°12′26.3″S; 38°02′30″W), and another site, colonized by the same grass, but outside the pivot limits and, thus, not affected by irrigation (05°12′27.5S; 38°02′30.7″W).

The area under pivot is irrigated 12 h day$^{-1}$, receiving approximately 0.44 mm h$^{-1}$, with a total of 5.28 mm day$^{-1}$ and 1927.2 mm year$^{-1}$. Considering the historical rainfall average for the past 25 years, which was 748.7 mm, the irrigated area has received a total of approximately 2700 mm year$^{-1}$ via both irrigation and pluvial precipitation.

On the irrigated area the cattle remained for 12 h day$^{-1}$, while on the non-irrigated area animals stayed for the remaining 12 h of the day. This area is used for resting, circulation and it is where the water troughs are.

The irrigated area has a size of 50 ha, and has been under irrigation for about 23 years and cultivated with tifton grass for 10 years. Urea and single super phosphate are applied through fertigation, the former being applied in each grazing cycle. The organic fertilization is performed with animal manure from the farm in both areas. Agricultural machinery and implements are used during the haying season. Before pasture implementation, corn was grown in the area for nearly 5 years, with tillage using a plow and harrow to a 20 cm depth.

Soil sampling was performed in July 2011, with eight replications in three soil layers; 0–20, 20–40 and 40–60 cm, totalizing 48 samples (2 treatments × 3 layers × 8 replications). Undisturbed soil samples were collected in plastic bags, labeled, air dried, ground and sieved $< 2$-mm order to obtain a totally homogenized, air-dried soil. Four undisturbed soil samples were also collected in each area, using cylindrical samplers (98.175 cm$^3$), in the layers of 0–20 and 20–40 cm. In the laboratory the soil samples were analyzed for particle size distribution, soil particle density, soil bulk density, total porosity, macroporosity (pores with diameter $\geq 50$ μm, applying matric potential of $-6$ kPa), microporosity (pores with diameter $< 50$ μm, total porosity minus macroporosity), soil air permeability, soil resistance to penetration, aggregate stability and pore continuity indices.

### 2.2. Analyses

The particle size distribution was determined by the pipette method (Gee and Bauder, 1986), using chemical (sodium hexametaphosphate) and physical (fast agitation for 10 min) dispersion. Soil particle density was determined by the volumetric flask method (Blake and Hartge, 1986). Soil bulk density and soil particle density values were used to calculate total porosity with Eq. (1), Libardi (2012),

$$\alpha = \left(1 - \frac{\rho_s}{\rho_p}\right), \tag{1}$$

where $\alpha$ is total porosity (cm$^3$ cm$^{-3}$), $\rho_s$ and $\rho_p$ the soil bulk and soil particle densities, in g cm$^{-3}$, respectively. Total porosity was divided into micro and macroporosity by applying a matric potential of $-6$ kPa on the undisturbed soil samples (with this tension, pores with diameter $\geq 50$ μm are emptied), measuring the volume of water remaining in the sample, which is equal to the micropores volume. From the total porosity, macroporosity was calculated by difference. For soil air permeability, undisturbed soil samples were placed on a tray for saturation, through gradual elevation of the water level. After that, samples were placed on the tension table and subjected to five matric potentials: $-2$, $-6$, $-10$, $-33$ and $-100$ kPa. After equilibrium, soil samples had their masses measured and then the soil air permeability was determined (Kirkham, 1946). Soil air permeability ($K_{air}$) was determined using the falling head method (Kirkham, 1946; Neves et al., 2007; Silva et al., 2009; Silveira et al., 2011). For this determination, a permeameter composed of 30-L air cylinder, pressure transducer and a data acquisition system was used. The method is based on the quantification of the decrease in pressure versus time, which is proportional to the air flow crossing the soil sample. The air permeability coefficient ($K_{air}$) was determined using Eq. (2), Kirkham (1946),

$$K_{air} = \frac{L\eta\eta}{AP_{atm}} \times |S|, \tag{2}$$

where $K_{air}$ is the soil air permeability coefficient (m$^2$), $V$ the volume of air in the reservoir (m$^3$), $\eta$ the air dynamical viscosity (Pa s), $L$ the height of the cylindrical sampler (m), $A$ the transversal section of the soil sample (m$^2$), $P_{atm}$ the atmospheric pressure (Pa) and $S$ the angular coefficient of the linear regression of the pressure (ln of the pressure) as a function of time. The aeration porosity ($\varepsilon_{air}$) was