Infillings in irrigated soils cultivated with annual and perennial crops in the Apodi Plateau, Northeastern Brazil

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Abstract
Irrigated agroecosystems have some particularities that reflect on the nutrient cycling and energy fluxes differently from non irrigated areas and the efficient and rational use of these areas is highly recommended, but generally do not occur. Within this context, the aim of this work was to evaluate the consequences of the irrational use of irrigated systems under different conditions of soils, cropping, and management. We studied micromorphological properties of calcareous soils, using microanalysis techniques for different situations of management in an irrigated area located in the Apodi Plateau, state of Ceara, Brazil. We selected four cultivated areas and their respective native vegetation areas. The selection criteria considered the time of use, cropping regime (annual=corn and beans in succession and perennial=bananas, grass and guava) and irrigation systems (microsprinkler or central pivot). Soil blocks (5×10 cm) were collected from 5-15, 15-25 and 25-35 cm layers and pedological features at optical and electronic microscope level observed using SEM-EDS. It was possible to associate the frequency and types of infillings with the soil management, with a tendency for the frequency to be higher for the cultivated area, except for Gr. Generally, for cultivated sites the types are between dense complete (DC) and dense incomplete (DI), with voids in the CB area, and in natural situations loose continuous (LC) or loose discontinuous (LD) fabrics. The SEM mapping and EDS data showed infillings voids and a greater proportion of quartz grains occupying the voids with a composition similar to the matrix. Grains of iron oxide appeared in the infilling probably due to the weathering of calcareous rocks. It is possible that a natural susceptibility to infilling formation in the soils studied associated with their genesis, management and irrigation, intensifying the frequency and types of infilling. Certainly other physical properties related to water movement and root development will be compromised.

Key Words
Soil quality, soil structure, soil management, micromorphology, microanalysis, calcareous soils.

Introduction
Investments have been applied to the enlargement of irrigated areas in the northeastern region of Brazil. This fact is strategically important, since they promote better money distribution and improve the employment generation, decreasing social differences and increasing life quality in one of the poorest region of Brazil. However, the expandsion of irrigated areas is limited. Considering all existing and future available water for irrigation, only 5% of the total area of the northeastern region can be irrigated. Thus, the efficient and rational use of these areas is highly recommended, which generally do not happen.

Irrigated agroecosystems have some particularities of nutrient cycling and energy fluxes different from non irrigated areas. Normally, the intensity of these processes is higher when compared to natural conditions, basically due to higher exportat of nutrients and biomass production (higher productivity and number of crops), higher necessity of agricultural practices, and higher external input (fertilizers, herbicides, insecticides, and fungicides). Furthermore, the hydrological behaviour is changed by the number and intensity of wetting and drying cycles of soils. Inadequate soil management practices have been noticed in some irrigated areas in the northeastern region of Brazil, reflecting environmental constraints due to soil salinity, soil compaction, and soil and water pollution by agricultural chemicals. Adopting any additional management practice aiming to reclaim these areas can result in the decrease of their sustainability and efficiency.

Within this context, studies must to be conducted in order to evaluate the consequences of the irrational use of the irrigated systems under different soils conditions, cropping, and management. Hence, the objective of this work was to evaluate the micromorphological properties of calcareous soils, using microanalysis techniques, for an irrigated area located in the Apodi Plateau, State of Ceara, Brazil.

Methods
The study was carried out in the Jaguaribe-Apodi irrigated area, located in the Apodi Plateau, municipality of Limoeiro do Norte (5° 06' S and 37° 52' W), to 199 km from the capital Fortaleza, Ceara (Figure 1). The climate classification is BSw'h', according to Köeppen classification, with annual means of temperature and rainfall of 28.5 ^{o}C and 772 mm, respectively. The main cropping systems are fruits species (e.g. bananas, melon, guava, etc) and grains (e.g. maize, beans, and sorghum). The irrigation was performed either by localized irrigation system, by using microsprinklers, or using a central pivot irrigation system. The central pivot system has been replaced due to high water demand. For this study, we selected four cultivated areas and their corresponding natural vegetation areas. The criteria for selection considered the time of use, cropping regime (annual and perennial), irrigation systems (microsprinkler or pivot central), and quality of technical management (Lacerda and Oliveira 2007).

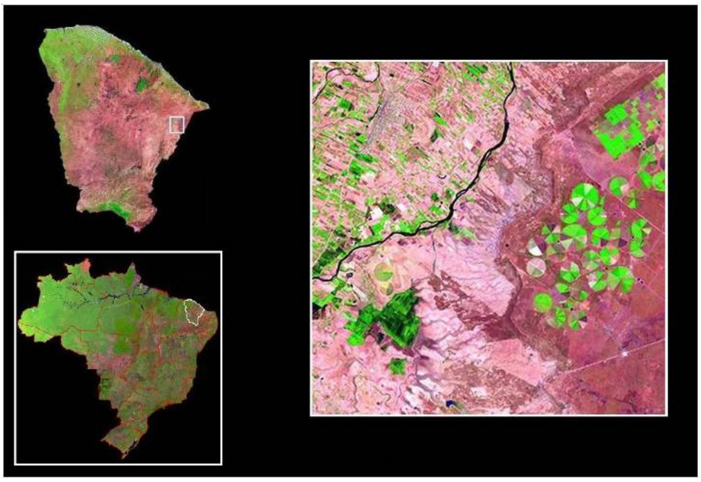

Figure 1. Location of Apodi Plateau and the Jaguaribe-Apodi irrigated area, Limoeiro do Norte-CE, Brazil.

Soil blocks (5×10 cm) collected at 5-15, 15-25 e 25-35 cm layers were impregnated with a 1:1 crystic resin: stiren mix poured onto samples under atmospheric pressure, followed by vacuum oven treatment at 50 °C for 2 h. Impregnated samples were cut into slabs of 0.5 cm thickness by using a diamond saw, and polished with corundum abrasives from 250 down to 600 mesh. After ultrasonic cleaning, the polished blocks were mounted onto glass slides followed by polishing and hand-finishing to produce 30 nm thick sections. No cover slips were used. Thin sections were examined under a Zeiss polarizing microscope (Optical Transmitted Microscopy—OTM level) using an attached Pentax camera fitted with a Zeiss exposure-meter. Pedological features at OTM level were analysed using standard micromorphological techniques (Bullock *et al.* 1985), and the selected areas described were submitted to SEM-EDS analysis. The microstructure and submicrostructure were investigated using a JEOL 6400 scanning electron microscope coupled with an energy dispersive X-ray detector (SEM/EDS), following the recommendations of Bisdom and Ducloux (1983). A flat ultrapolished, uncovered, thin section of approximately 12 cm^2 was analysed for the elemental distribution of Ca, Mg, K, Si, Al, Fe, Mn and Ti using energy dispersive spectrometry (EDS). In this paper, only pedofeature infillings are reported.

Results
Firstly, it is possible to associate the frequency and types of infillings with soil management (Table 2). Infillings are more abundant for cultivated soil, except for Gr area. Current management was less intensive in G and B areas; it used to be intensive with annuals and sprinkler irrigation by central pivot. The higher frequency at the deepest layers (25-35 cm) occurred with all cultivated areas, except the CB area, which has similar frequency for all evaluated layers. Probably cultivation affects infilling formation. The Gr area had the higher difference between cultivated and non-cultivated areas and, also, within layers (5-15 and 15-25 to 25-35 cm) mainly due to the cultivated situation.

Also, it is possible to associate the types of infillings with the influence or not of cultivation. In the cultivated areas the types varied from dense complete (DC) to dense incomplete (DI), what means that voids are completely unfilled as is the case of voids from the CB area (Figure 1). Under natural conditions, the types showed grains, aggregates, crystals or excrements distributed throughout the void and are loosely packed (loose continuous=LC) or irregularly distributed, isolated or in clusters (loose discontinuous=LD) (Figure 2).

Table 1. Location, soil classification and history of use of cultivated areas in the Jaguaribe- Apodi irrigated area, Limoeiro do Norte-CE, Brazil.

Area	Soil classification*	Historic
Corn/beans (CB) (5°10'9" S and 37°58'58" W)	Red Latosol Eutrofic cambissolic	Area with 26 ha but in the moment of soil collection only 6 ha were under cultivation. It has been cultivated for 20 years with corn and beans in succession. The irrigation was performed by pivot central system. Chemical fertilizers used were urea and ammonium sulphate. Soil preparation was done by using subsoiler followed by disc harrow and disc plow. There was use of herbicides and insecticides (Lannate BR, 7.5 L/ha/cycle). Soil from natural vegetation collected near cultivated area is Red Argisol Eutrofic latossolic.
Guava (G) (5°09'29" S and 37°59'36" W)	Cambissol Haplic Tb Eutrofic Tipic	Area with 6 ha that has been cultivated with guava for 7 years by adopting localized microsprinkler irrigation system. This area was previously cultivated during 10 years with annual crops and sprinkler irrigation by pivot central. Organic (caprine manure, 20 L/plant, applied each 2 months) and chemical fertilizers (Urea – 30 g/plant, Potassium chloride – 50g/plant, Magnesium chloride – 30 g/plant, Calcium nitrate – 30 g/plant and MAP – 300 g/plant) were applied in each cropping cycle. Soil preparation was usually done by subsoiling, but only a mechanical mow is current used in the wet season. Soil from natural vegetation collected near cultivated area is Cambissol Haplic Tb Eutrofic latossolic/Tipic.
Grass (Gr) 5°12'54" S and 38°01'52" W	Cambissol Haplic Ta Eutrofic Tipic	Area with 1,600 ha that has been cultivated for 10 years with *Cynodon niemfluesis*, adopting pivot central irrigation system. This area was previously cultivated with corn during 5 years. Chemical fertilization was done by applying urea four times per year (100 kg/ha each time), one application of MAP (50 kg/ha), and one application of simple superphosphate (50 kg/ha). The organic fertilization was performed in the same area by animals (10 animals/ha) grazing 12 hours daily. Disease and pests did not happen. Machinery was used in the hay making process. Soil from natural vegetation collected near cultivated area is Cambissol Haplic Ta Eutrofic Tipic.
Bananas (B) (5°9'15" S and 37°59'55" W)	Cambissol Haplic Ta Eutrofic Tipic	Area with 287 ha that has been cultivated for 10 years with banana adopting localized microsprinklers irrigation system. This area was previously cultivated with vegetables during 5 years. There was application of caprine manure (20 L/plant/week) and liquid organic compost (600L/plant/week). It was used chemicals to control pathogens, insects and weeds. Soil chemical fertilization was performed monthly by using urea, potassium and magnesium sulphate. Each 10 years intervals the plot is renewed, and for this purpose soil preparation is done by using subsoiler and disc harrow. Soil from natural vegetation collected near cultivated area is Cambissol Haplic Ta Eutrofic Tipic

*Soil classification using Brazilian System.

Table 2. Frequency and types of soil infillings from irrigated area under different management situations and areas under natural vegetation in the Jaguaribe-Apodi irrigated area, Limoeiro do Norte-CE, Brazil.

Area/Sample	Layers (cm)		
	5-15	15-25	25-35
Corn/Beans (CB)	Fq / DI-LC	Fq / DI-LC	Fw / DI-LC
Corn/Bean natural vegetation (CBNV)	VFw / LC-LD	Fq / LC-LD	VFw / LC-LD
Guava (G)	Fq / DI-LC	C / DI-LC	C / DI-LC
Guava natural vegetation (GNV)	Fq / LC-LD	Fq / LC-LD	C / LC-LD
Grass (Gr)	Fq / DI-LC	Fq / DI-LC	D / DI-LC
Grass natural vegetation (GrNV)	C / LC-LD	VD / LC-LD	C / LC-LD
Bananas (B)	Fq / DI-LC	D / DI-LC	D / DI-LC
Bananas natural vegetation (BNV)	D / LC-LD	C / LC-LD	D / LC-LD

Frequency: VD: Very dominant (>70%); D: Dominant (50-70%); C: Common (30-50%); Fq: Frequent (15-30%); Fw: Few (5-15%) and VFw: Very few (<5%). Types of infillings: DC: Dense complete; DI: Dense incomplete; LC: Loose continuous; LD: Loose discontinuous. According to Bullock *et al* (1985).

The mapping and EDS data showed the void infillings with a greater proportion of quartz grains occupying the voids and a composition similar to the matrix. Grains of iron oxide occurs in the infilling probably from concentration due the weathering of calcareous rocks. The iron oxide in the matrix is relatively high for soils considered equivalent to Inceptsols, but did not occur in discrete units like in the infillings.
Naturally, the studied soils seem to be susceptible to infilling formation if we consider their frequency under natural conditions. We consider what material can be associated with the parent material and consequent natural chemical properties. The developed soils exhibit the influence of calcareous rocks and are dispersible. The low stability of aggregates and loam texture of soils can contribute to the production of fine particles and small clods that occupy the voids, this increasing the frequency and types of infillings.

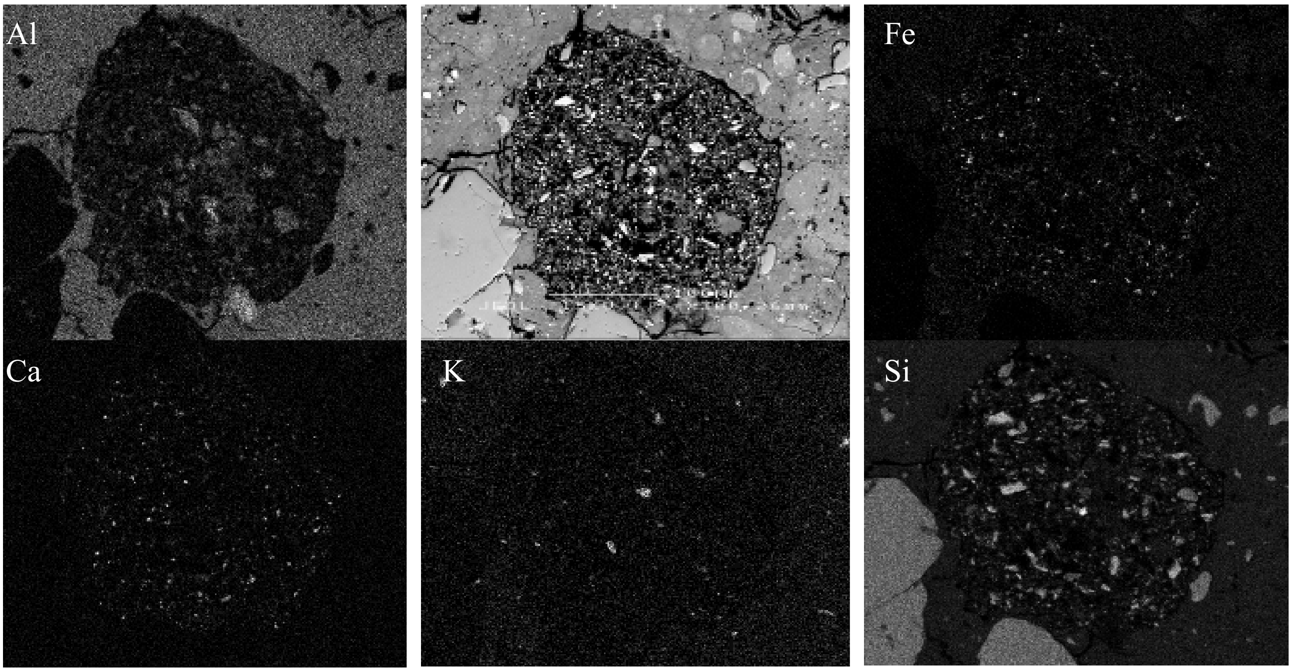

Figure 1. Dense complete void filling (upper and central photo) and Al, Fe, Ca, K and Si in soil from a Corn and Bean (CB) area located in the Jaguaribe- Apodi irrigated area, Limoeiro do Norte-CE, Brazil.

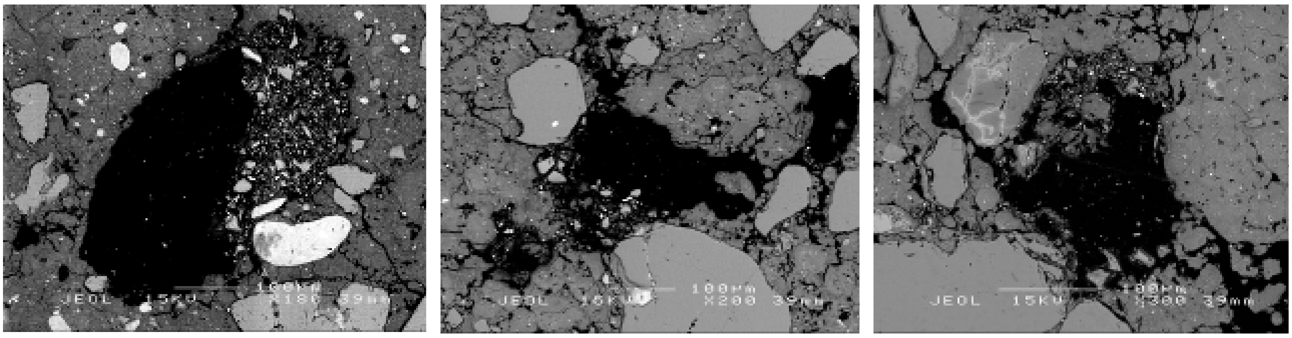

Figure 2. Void with loose continuous and discontinuous filling from soil under natural vegetation of bananas (NVB) area located in the Jaguaribe- Apodi irrigated area, Limoeiro do Norte-CE, Brazil.

Conclusion
There is a natural susceptibility to infilling formation in the studied soils which is probably associated with their genesis and the management. Irrigation increased the frequency and types of infilling. Certainly physical properties related to water movement and root development will be compromised by void infilling.

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