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Impact of soil management on the physical properties of an ferralsol from the 'Campos de Cima da Serra' region, Rio Grande do Sul

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Abstract: The expansion of cultivation areas, especially in the last decade, has changed the landscapes of 'Campos de Cima in Serra' of Rio Grande do Sul state, where livestock activity has been developing for 300 years. The introduction of silviculture, grain crops, and orchards, in addition to the cultivation of vegetables, have imposed different managements on the soils, ranging from direct planting to the use of rotary hoes. This work sought to evaluate the impact of different types of soil management on the physical properties and water infiltration capacity of a ferralsol, typical of this region of the north of Rio Grande do Sul state. The soil under the management of native grazing fields showed lower particle and bulk densities and resistance to penetration, while soil planted on garlic crops showed greater resistance to penetration, particle and bulk densities, and lower total porosity and macroporosity. The average infiltration speed was 29.2 mm·h^{-1} for the native field under grazing (T1), 65.4 mm·h^{-1} for planting on soybean straw (T2), and 20.0 mm·h^{-1} for planting on garlic crop (T3). It was observed that intensive management, such as the use of the rotary hoe, had a considerable negative impact on the physical properties and the speed of water infiltration in the soil and, consequently, potential damage to the replenishment of underground deposits, when compared with direct planting and the native field.

Keywords: Soil management, Water infiltration, Soil penetration, Infiltration speed.

Resumo: *A ampliação das áreas de cultivo, principalmente na última década, modificou as paisagens dos Campos de Cima da Serra do RS, onde há 300 anos desenvolve-se a atividade pecuária. A introdução da silvicultura, das lavouras de grãos e de pomares, além do cultivo de olerícolas, têm imposto aos solos diferentes manejos, que vão do plantio direto até o uso de enxada rotativa. Este trabalho buscou avaliar o impacto de diferentes tipos de manejo do solo sobre as propriedades físicas e capacidade de infiltração de água de um latossolo vermelho, típico desta região do norte rio-grandense. O solo sob o manejo de campo nativo com pastejo apresentou menores densidades real e aparente e resistência à penetração, enquanto o solo com plantio sobre lavoura de alho apresentou maiores resistência à penetração, densidades real e aparente e menores porosidade total e macroporosidade. A velocidade de infiltração média foi de 29,2 mm·h^{-1} para o campo nativo sob pastejo (T1), 65,4 mm·h^{-1} para o plantio sobre palha de soja (T2) e 20,0 mm·h^{-1} para o plantio sobre lavoura de alho (T3). Observou-se que manejos intensivos, como o uso da enxada rotativa, apresentaram impacto negativo considerável nas propriedades físicas e na velocidade de infiltração de água no solo e, consequentemente, potencial prejuízo ao reabastecimento dos depósitos subterrâneos, quando comparados com o plantio direto e o campo nativo.*

Palavras-Chaves: *Manejo de solo, Infiltração, Penetração do solo, Velocidade de infiltração.*

1. INTRODUCTION

In the 'Campos de Cima da Serra' region of Rio Grande do Sul state, diverse soil management kinds are used in agricultural practices, especially with the increasing acreages in the last decade, which were formerly occupied by native forest and pasture. In the decade of 2000-2010, there was an intensification of the anthropic interventions on the soil of this region, highlighting the advance of grain crops and, to a lesser degree, the cultivation of vegetables [1-2].

This expansion of crop acreage in areas that were occupied by pasture causes important anthropomorphic changes in the soil, capable to impact its infiltration capacity, which can be increased or decreased according to the adopted management kind [3]. Relative to the native pastures of South Brazil, Pillar et al. [2] commented that these ecosystems have a high diversity of animal and plant species, also citing the possible loss of a significant part of this biodiversity due to the agricultural practice without the application of preservation techniques.

Water infiltration into the soil, beyond supplying the edaphic water – water located above the level of groundwaters and that can be absorbed by the plants – ensure the replenishment of springs and the maintenance of the underground water reservoirs [4]. The water-soil relation is paramount for sustainable food production. Inadequate soil management can not only compromise its fertility and conservation but can also compromise the hydrological flow, insofar it restricts the water replenishment, through infiltration, of the underground reservoirs [5].

The water infiltration capacity of the soils has enormous importance from the agronomic and environmental standpoints, especially regarding the infiltration of rainfall water. This parameter is decisive when considering soil conservation insofar as this avoids or minimizes superficial runoff and the consequent erosion process, as well as ensuring an adequate supply of water to plant roots, even the larger ones. Moreover, higher infiltration capacities maintain the groundwater stocks and the replenishment of aquifers. Thus, water infiltration in the soil is an essential component of the continental phase of the hydrologic cycle [5-6]. The water infiltration speed is not constant, it varies with the infiltration volume. According to Bertoni and Lombardi Neto [7], infiltration is the water movement throughout the soil profile; the higher it is, the smaller is the degree of surface runoff.

Several methods are employed in the determination of the soil infiltration capacity, such as laboratory experiments, use of artificial rain with constant height, field experiments with a fixed height from the water-free surface, measurements during rainfall under natural conditions, among others [6,8].

Several soil management kinds are employed in the 'Campos de Cima da Serra' region, such as the use of plowing and harrowing, crop rotations, alternate use of the area for crop panting and grazing, among others. The different soil managements used in the agricultural practices impact directly the soil infiltration capacity. The effect of the presence of pasture is reported in the literature, with conflicting results. The evaluation of this physical parameter of the soil and their behavior under different managements are relevant due to the economic and environmental aspects since both the soil suitability for agricultural use and the overall water availability are strongly influenced by this property [5,9].

Troeh and Thompson [6] cited the importance of protecting the soil against the direct impact of rainfall, which can over time destroy the soil aggregates, creating an impermeable surface crust and lowering the water infiltration capacity and speed. A low permeability reduces the water infiltration and increases the surface runoff, enhancing soil erosion. Thus, a dense vegetation cover that intercepts rainfall would be the most adequate for the soil. Coverings made of crop residues, such as straw, may also be used for soil protection. Moreover, the use of straw as a soil covering improves soil humidity, increasing water infiltration and avoiding excessive soil drying. As observed by Baumhardt and Lascano [10], the use of crop residues as covering increased the water infiltration and reduced its evaporation in the tested soil. Steiner [11] also commented that covering made of crop residues reduces water evaporation in amounts that are proportional to the volume of the plant material, and not its mass.

Even when the soil is plowed, if the plowing depth is reduced (8-10 cm instead of the conventional 15-20 cm), allowing for the presence of crop residues in the soil surface, the runoff is reduced, when compared to the conventional plowing system. This occurs because, even partially, the soil was protected by the residue covering [6].

The importance of the soil management system – conventional (plowing and harrowing), minimum tillage, no-till planting, among others – is one of the major factors that influence the soil infiltration capacity. Troeh and Thompson [6], stated that conventional management causes surface runoff and increases the erosion rates relative to the minimum tillage and the no-till planting. The authors also commented that the planting of pasture tends to conserve more the soil and maintain its properties relative to water transport and accumulation.

The transition from native pasture to systems aimed at the production of grains and vegetables consequently causes changes in soil management, which may imply major changes in the infiltration capacity of the soil and, eventually, in changes in the physical and hydrologic aspects of the managed soil [4,7].

Thus, the present work aimed to evaluate the impact of three different management kinds, commonly used in the 'Campos de Cima da Serra' region of the Rio Grande do Sul state, on the physical properties and water infiltration and capacity of a ferralsol from the same region.

2. MATERIALS AND METHODS

2.1. Soil tested and characteristics of the rural property

The studied soil was located in the municipality of Campestre da Serra, Rio Grande do Sul state. The agricultural activity of the property was based on crop and livestock integration and the valorization of the native pasture. In the summer period, soybean and maize were cultivated, in a rotation system. In winter, black oat (*Avena strigosa*) was cultivated in most of the areas to be used in cattle grazing, resulting in the presence of large quantities of residual straw. Maze (*Triticum sativum*) was cultivated in a smaller acreage each winter, also in a rotation system. In a six-hectare area, in winter, garlic (*Allium sativum*) was cultivated after the harvesting of the soybean. With exception of the garlic crop area, the cultures were grown using direct plating, without the use of terraces. The garlic crop was irrigated by aspersion and cultivated in beds; the soil was prepared by harrowing, followed by plowing with a rotary hoe.

2.2. Soil management kinds tested

Three areas of the property with distinct soil management kinds and similar soil kind and slope were selected, with the determination of the altitude relative to the sea level and the geographical coordinates. The characteristics of the areas relative to the soil management kind are presented in Table 1.

Table 1: Treatments employed (management kinds), altitude, and geographical coordinates of the studied areas.

Treat.	Management kind	Alt. (m)	Geographical coordinates
1	Native pasture with rotated grazing (Voisin system)	840	28°44'00" S 51°06'35" W
2	Direct planting of black oat (on soybean straw), soil never plowed	870	28°44'02" S 51°05'43" W
3	Direct planting of black oat (on soybean straw) after plowing and harrowing, area was previously a garlic cultivation	870	28°43'26" S 51°05'27" W

2.3. Soil characterization

Ten soil subsamples were collected in each area, in the sampling depths of 0-10 and 0-20 cm; the subsamples were mixed and three samples were collected to carry out the soil characterization.

The granulometric and chemical (soil fertility) analyses were carried out following the procedures described by Tedesco et al. [12]. The determination of the physical properties (particle and bulk densities, soil porosity) was carried out following the methods described by Embrapa [8].

For each treatment, soil samples were collected using volumetric rings with a volume of 100 cm^3. The samples were collected at depths of 10 and 20 cm, with three replicates, being the rings positioned perpendicularly to the wall of the hole dug.

The soil resistance to penetration was also evaluated for the three treatments in the depth range of 0-60 cm using a digital penetrometer (penetroLOG PLG 1020, Falker, Brazil) and a cone size 2 (diameter of 12.83 mm). Three points were measured for each treatment.

2.4. Measurement of the water infiltration capacity and infiltration speed in soil

To measure the infiltration capacity of the treated soils, it was used a ring infiltrometer, which is an equipment constituted by two concentric metal rings, the inner one with a diameter of 25 cm (effective infiltration area of 490.8 cm^2) and the outer with 50 cm, both with a height of 25 cm. 15 cm were stuck to the ground.

Tap water was added to the two compartments and the height of liquid in the inner compartment was monitored. Measurements were taken every 5 min in the first hour and after each hour, up to 5 h.

The data of accumulated infiltration (I) and accumulated time (t) were plotted to observe any trend between these parameters. The infiltration speed (VI) was calculated as the ratio between the accumulated infiltration and the accumulated time (VI = I/t) for each time-infiltration pair. The immediate infiltration speed (VI') is characterized as the increment of infiltration, being determined as the ratio between ΔI and Δt.

2.5. Experimental design and statistical analysis

The experimental design was completely randomized, with three treatments. All parameters were evaluated in three replicates. The obtained data underwent analysis of variance (ANOVA) and the means were compared by Tukey's multiple range test at 5% probability ($\alpha = 0.05$).

3. RESULTS AND DISCUSSION

3.1. Soil characterization

The soil studied was a ferralsol, a soil kind typical of the 'Campos de Cima da Serra' region of Rio Grande do Sul state. Ferralsols are generally well-drained, normally deep, with little to no increase in clay content with depth, with a gradual or diffuse transition between horizons [13]. Due to the high degree of weathering, these ferralsols have high amounts of kaolinite and iron oxides, which confers to the soil a low cation exchange capacity (CEC).

These characteristics render ferralsols highly acidic, with low nutrient supply, and prone to cause aluminum (Al^{3+}) toxicity to plants [13-14]. According to Streck et al. [14], ferralsols with high sand content or their mixture with basaltic material are recognized by the deposition of light-colored quartz grains in the drainage areas.

3.2. Fertility parameters and granulometry of the treated soils

The results of the chemical (fertility) parameters and the granulometry of the studied soils in the depths of 0-10 and 10-20 cm are presented in Table 2.

Table 2: Chemical and granulometric characterization of the studied soils at the sampling depths of 0-10 cm and 10-20 cm.

Parameter	T1		T2		T3	
	0-10	10-20	0-10	10-20	0-10	10-20
Clay (% m/v)	50	65	54	70	59	69
pH	4.6	4.6	5.7	4.8	5.9	5.3
pH-SMP	4.3	4.3	6.0	4.6	5.9	5.4
P ($mg \cdot dm^{-3}$)	1.3	1.3	4.7	2.4	50.6	15.0
K ($mg \cdot dm^{-3}$)	90.0	46.0	86.0	38.0	264.0	166.0
OM[1] (% m/v)	5.3	4.2	6.0	4.4	5.3	4.6
Ca ($cmol_c \cdot dm^{-3}$)	0.5	0.2	7.2	1.9	11.1	7.5
Mg ($cmol_c \cdot dm^{-3}$)	0.4	0.1	5.1	2.0	4.4	3.3
Al ($cmol_c \cdot dm^{-3}$)	5.9	6.5	0.0	3.4	0.0	0.5
H+Al ($cmol_c \cdot dm^{-3}$)	30.7	30.7	4.4	21.8	4.9	8.7
Base saturation (%)	3.6	1.3	74.1	15.5	76.7	56.4
Al saturation (%)	84.3	94.2	0.0	45.9	0.0	4.3
Eff. CEC[2] ($cmol_c \cdot dm^{-3}$)	7.0	6.9	12.5	7.4	16.2	11.7
CEC[2] pH 7 ($cmol_c \cdot dm^{-3}$)	31.8	31.1	16.9	25.8	21.1	19.9
Mn ($mg \cdot dm^{-3}$)	26.0	11.0	4.0	4.0	5.0	13.0
Cu ($mg \cdot dm^{-3}$)	5.4	6.0	1.8	3.2	2.2	3.3
Zn ($mg \cdot dm^{-3}$)	1.4	0.5	1.5	0.5	6.5	3.7
B ($mg \cdot dm^{-3}$)	0.3	0.2	0.3	0.3	0.5	0.5
S ($mg \cdot dm^{-3}$)	4.7	2.8	9.6	12.3	5.7	21.5
Na ($mg \cdot dm^{-3}$)	6.0	8.0	6.0	4.0	8.0	12.0
Granulometric analysis						
Clay (wt. %)	46	52	48	54	50	56
Silt (wt. %)	31	28	31	27	32	25
Sand (wt. %)	23	20	21	19	18	19

[1] – Organic matter; [2] – Cation exchange capacity. T1 – native pasture with grazing; T2 – planting on soybean straw; T3 – planting on former garlic cultivation (soil plowed and harrowed).

It was possible to observe, according to Table 2, that T1 has had higher organic matter (OM) contents in both depths. Higher OM contents increase the overall soil water retention capacity, improving its structure and porosity. Relative to T2, the presence of straw increased the OM contents, especially in the shallower soil depth (0-10 cm) relative to the other treatments. This higher OM content is probably the result of straw residues accumulating throughout the production cycles in succession (soybean, black oat, maze) during crop rotation.

It is also noteworthy the high values of Al saturation, which are typical for this soil kind. In T1, the Al saturation values ranged between 84.3 and 94.2% for the depths of 0-10 and 10-20 cm, respectively. In the treatments T2 and T3, the Al saturation was zero for the depth of 0-10 cm; for the depth of 10-20 cm, this parameter presented distinct behavior: 45.9% for T2 and 4.3% for T3. These results are very probably the results of the management kind. Whereas in T2 the liming was carried out only superficially, in T3 the liming requirements were much higher and the incorporation was carried out vigorously using plowing in depths as low as 20 cm. It is also important to observe that, in T2, even if the liming was not followed by incorporation by plowing, the Al^{3+} contents were neutralized in depths down to 10 cm.

Relative to base saturation, it was low in T1 and decreased with the increase in depth (3.6% in 0-10 cm and 1.3% in 10-20 cm). T2 and T3 have had similar base saturation percentages, (74.1 and 76.7%, respectively) in the depth of 0-10 cm; however, this behavior changed in the depth of 10-20 cm, being the base saturation much higher in T3 relative to T2. This is the result of the liming incorporation by plowing, in a similar way to the Al saturation decrease.

The effective CEC was higher in the treatment T3 in both depths, followed by T2, and, finally, by T1. Considering that the effective CTC is the sum of the major cations present in the soil (K^+, Na^+, Ca^{2+}, Mg^{2+}), the lower values for T1 are the result of the intrinsic low availability of nutrients in this soil type. The higher values for the other treatments are the direct result of liming and fertilization. The treatment T3 presented the highest values due to the addition of large amounts of fertilizers and liming, especially because garlic is a demanding culture, like most vegetable crops [15].

According to the granulometric analysis (Table 2), the soils of the treatments T1 and T2 were classified as clay loam in the depth of 0-10 cm and as clay in the depth of 10-20 cm. The soil of T3 was classified as clay in both depths. This classification may also be a result of the management history of each soil. In T1 and T2, the soils were never plowed, keeping the particle structure and texture, unlike the soil of T3, which underwent extensive harrowing and plowing. Considering that, before this study, the soil of T3 underwent three consecutive cultivations of garlic, followed by soil preparation as considered the standard management for this crop, this soil presented inversion and a mixture of soil horizons. This was intensified by the extensive plowing down to 20 cm, used in the construction and preparation of the planting beds for garlic cultivation.

There are reports in the literature citing that clay loam soils tend to have higher infiltration speeds than clay soils due to the lower clay-sand proportion, increasing the overall water draining capacity [13].

3.3. Effect of management on the physical properties of the soil

The results of the physical characterization of the soils are presented in Table 3.

Table 3: Results of particle density (PD), bulk density (BD), total porosity (TP), macroporosity (MAP), and microporosity (MIP) of the treated soils.

Treat.	Depth (cm)	PD ($g \cdot cm^{-3}$)	BD ($g \cdot cm^{-3}$)	TP (%)	MAP (%)	MIP (%)
T1	0-10	2.56^{c}	1.09^{c}	30.76^{a}	27.46^{a}	3.29^{b}
	10-20	2.67^{a}	1.16^{abc}	25.00^{cd}	21.53^{c}	3.46^{b}
T2	0-10	2.55^{c}	1.12^{bc}	30.15^{a}	27.85^{a}	2.30^{c}
	10-20	2.63^{b}	1.14^{abc}	25.33^{c}	21.01^{c}	4.32^{a}
T3	0-10	2.56^{c}	1.19^{ab}	27.65^{b}	24.28^{b}	3.36^{b}
	10-20	2.67^{a}	1.22^{a}	23.00^{d}	19.37^{c}	3.62^{b}

Means in column followed by the same superscript letter do not present statistical difference by Tukey's multiple range test at 5% probability ($\alpha = 0.05$). T1 – native pasture under grazing; T2 – planting on soybean straw; T3 – planting on former garlic cultivation (soil plowed and harrowed).

Silveira et al. [16] commented on the effect of management in soil particle and bulk densities, citing that soil plowing tends to increase the overall soil bulk density. The particle density is more closely related to the granulometric distribution of the soil, and tends to increase with increasing depth due to the changes in soil horizon; however, plowing and harrowing may have a destructive effect on soil aggregates, 'milling' the soil particles and reducing their size. Smaller particles tend to pack more closely, increasing the overall soil particle density in heavily managed soils [3,9,13].

Considering the total porosity, the treatments T1 and T2 were quite similar in the depth of 0-10 cm, whereas for T3 it was smaller. This parameter decreased with the increase in depth, being smaller in the depth range of 10-20 cm. It is important to take into account that soil porosity is linked to the arrangement of the soil aggregates, smaller porosity values are the result of a more compact structure, which is characteristic of the deeper soil layers as the result of the pressure caused by the overlying material. Excessive use of machinery also tends to compact the soil, reducing its porosity [5-6,13].

The microporosity has not followed a clear trend; statistical differences occurred as a function of the sampling depth rather than the management kind. Overall, there was no difference in the microporosity for the treatments T1 and T3. For T2, the microporosity increased with the depth, a reversed trend relative to the total porosity.

Soil microporosity is linked to the water retention capacity; soils that present a higher number of micropores tend to retain more water. The micropores also improve the overall water infiltration capacity by acting as capillary conductors for the water to flow through the soil profile [17].

The macroporosity values were higher in the shallower layer of the soil samples (0-10 cm), for all treatments. The treatments T1 and T2 have had the higher values, whereas the treatment T3 presented a lower macroporosity, differing statistically from the other treatments. On the other hand, there

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was no statistical difference among the treatments for the soil depth of 10-20 cm.

Macroporosity is related to soil aeration; macropores are mostly occupied by air, unlike the micropores, which are occupied by water due to the capillary effect. The presence of macropores is important to improve the oxygen availability to the roots and also to allow for an easier emergence of the seedlings [6-7]. Stone et al. [18] cited that soil compaction due to inadequate management may have an important effect on overall crop productivity. These authors also cited that, the smaller the soil density is, the lower is the soil resistance to penetration. Moreover, changes in the soil bulk density may end up influencing the soil particle size and aggregation (macro and microporosity).

3.4. Soil resistance to penetration

The soil resistance to penetration was evaluated in the depth range of 0-60 cm. The data of soil resistance to penetration for the three treatments is presented in Figure 1.

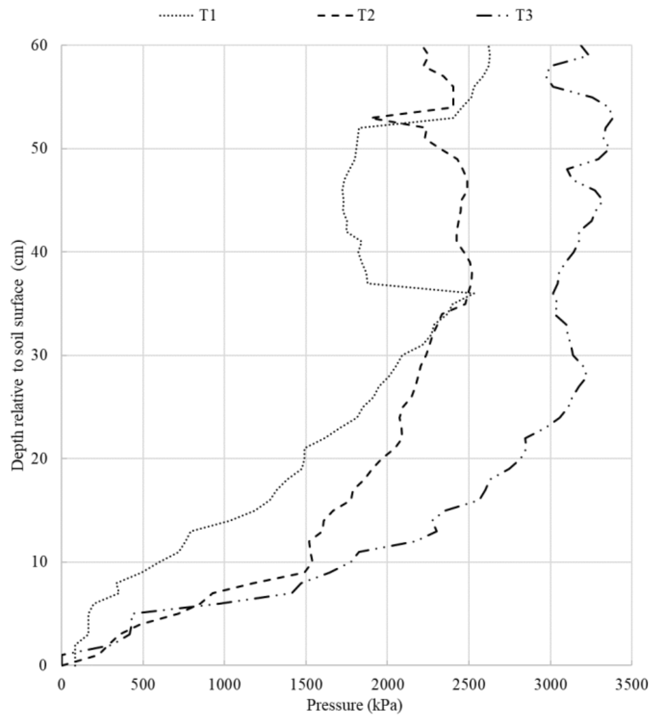

Figure 1: Soil resistance to penetration (kPa) as a function of the penetration depth for each treatment.

According to Figure 1, it is possible to observe that for T1 the values of resistance to penetration are smaller in nearly all of the profile (0-53 cm). It was also observed that the treatment T2 presented an intermediate resistance relative to the other treatments, but the values were similar in the range of 0-10 cm due to the superficial plowing of T2. The general trend was T3 presenting the highest resistance to penetration, indicating a more compact soil.

Soils that underwent extensive plowing tend to have their aggregated to re-accommodate, compacting even more and increasing the soil resistance to penetration. However, it is still a common-sense among several farmers that plowing unzips the soil, rendering it ‘softer’. According to Tormena et al. [9], soil management kind interferes directly in the soil resistance to penetration, its density, and porosity.

In terms of absolute values, for T3 the resistance to penetration reached 3,000 kPa at the depth of 37 cm and remain in this range down to 60 cm. On the other hand, T1 had 2,620 kPa as the highest value at the depth of 60 cm; there was also a region in which the resistance decreased, between 37 and 52 cm. The treatment T2 presented intermediate resistance to penetration values; the values were lower than T1 in the lower part of the profile (depths greater than 53 cm).

It is noteworthy the behavior of T3, whose soil has had a history of being plowed down only to the depth of 20 cm; this soil presented higher resistance to penetration and, thus, compaction, in the deeper parts of the profile than the other treatments, in the case, down to 60 cm.

3.5. Determination of the water infiltration speed in the soil

The results of water infiltration capacity, infiltration speed, and immediate average infiltration speed as a function of time are presented in Table 4.

Table 4: Water infiltration capacity (I, cm), average infiltration speed (VI, mm·h^{-1}), and immediate infiltration speed (VI', mm·h^{-1}) as a function of the accumulated time (T, min) of the tested soils.

T1 – Native pasture under grazing			
t (min)	I (cm)	VI (mm/h)	VI' (mm/h)
5	0.0	0.0	0.0
10	0.3	18.0	36.0
15	0.5	18.0	18.0
20	0.6	18.0	18.0
25	0.8	18.0	18.0
30	1.1	21.0	36.0
35	1.4	24.0	42.0
40	1.8	27.0	48.0
45	2.3	30.7	60.0
50	2.9	34.2	66.0
55	3.4	37.1	66.0
60	3.9	39.0	60.0
120	7.9	39.3	39.5
180	11.3	37.5	34.0
240	15.2	38.0	39.5
300	19.1	38.2	39.0
Average		29.2	41.3

T2 – Planting on soybean straw			
t (min)	I (cm)	VI (mm/h)	VI' (mm/h)
5	0.0	0.0	0.0
10	0.7	42.0	84.0
15	1.4	56.0	84.0
20	2.2	66.0	96.0
25	3.0	72.0	96.0
30	3.7	74.0	84.0
35	4.5	77.1	96.0
40	5.2	78.0	84.0
45	6.0	80.0	96.0
50	6.6	79.2	72.0
55	7.2	78.5	72.0
60	7.8	78.0	72.0
120	11.4	57.0	36.0
180	15.3	51.0	39.0
240	18.8	47.0	35.0
300	22.5	45.0	37.0
Average		65.4	72.2

T3 – Planting on former garlic cultivation (soil plowed and harrowed)			
t (min)	I (cm)	VI (mm/h)	VI' (mm/h)
5	0.0	0.0	0.0
10	0.1	6.0	12.0
15	0.2	8.0	12.0
20	0.4	12.0	24.0
25	0.5	12.0	12.0
30	0.6	12.0	12.0
35	0.7	12.0	12.0
40	0.8	12.0	12.0
45	1.1	14.7	36.0
50	1.5	18.0	48.0
55	2.0	21.8	60.0
60	2.6	26.0	72.0
120	6.6	33.0	40.0
180	10.7	35.7	41.0
240	15.1	37.8	44.0
300	19.5	39.0	44.0
Average		20.0	32.1

The calculated average infiltration speed was 29.2 mm·h^{-1} for T1, 65.4 mm·h^{-1} for T2, and 20.0 mm·h^{-1} for T3. It is possible to observe that, relative to T3, the average infiltration speeds of T1 and T2 were 46 and 227% higher, respectively. As stated by Mendonça et al. [19] higher infiltration rates are normally observed in areas with little anthropic activity. Denardin and Kochhannu [20] commented that soils managed under conservative techniques have water infiltration rates higher than soil prepared under conventional management.

The smaller infiltration speed observed in the soil plowed in three consecutive winters (T3) indicated a higher surface waterproofing. This may be caused by the destruction and rearrangement of soil structure, reducing its porosity due to the plasticity of the clay-silt system, generally occurring by compaction. This causes excessive surface runoff, eroding the soil and removing nutrients and OM from the topmost layer, reducing its fertility [5,19]. Another deleterious effect of the sharp reduction of the soil infiltration capacity is the decreased rate of replenishment of groundwaters situated under the soil, once the waterproofing effect reduces the water penetration and its accumulation; this effect may be potentialized in drought periods [4].

The regressions of water infiltration capacity for the studied soils as a function of time are presented in Figure 2.

According to Figure 2, the behavior of the infiltration capacity with time presented a similar trend in all treatments, with a starting non-linear trend in the first hour, which linearized over time, with a roughly linear pattern from the first hour on.

The behavior of the infiltration data over time was modeled by linear regression in treatments T1 and T3, with regression slopes of 0.0659 cm·min^{-1} (39.54 mm·h^{-1}) and 0.0679 cm·min^{-1} (40.74 mm·h^{-1}), respectively, and determination coefficients (R^2) above 0.99. On the other hand, the treatment T2 was fit by a quadratic equation (R^2 = 0.987), mainly because of the infiltration pattern of the first hour; the data from the second hour on have presented a quite linear behavior.

It was observable that, as the soil wets, the overall infiltration rate tends to reduce until reaching a constant value; this phenomenon occurs mostly during rainfall greater than 20 mm. Since the groundwater reservoirs are replenished by infiltration and accumulation through the soil profile [3,19], the soil management kind impact directly in both the infiltration and replenishment rates.

Thus, considering from an environmental and sustainable standpoint, the soil management to be adopted depends on the soil and climate characteristics, water availability and replenishment rates, and also the possibility of rotation of the management type. Areas above groundwaters or aquifers may require less aggressive soil management, or even remain as native pasture/forest to avoid imbalances in the hydrologic cycle, especially in areas prone to drought.

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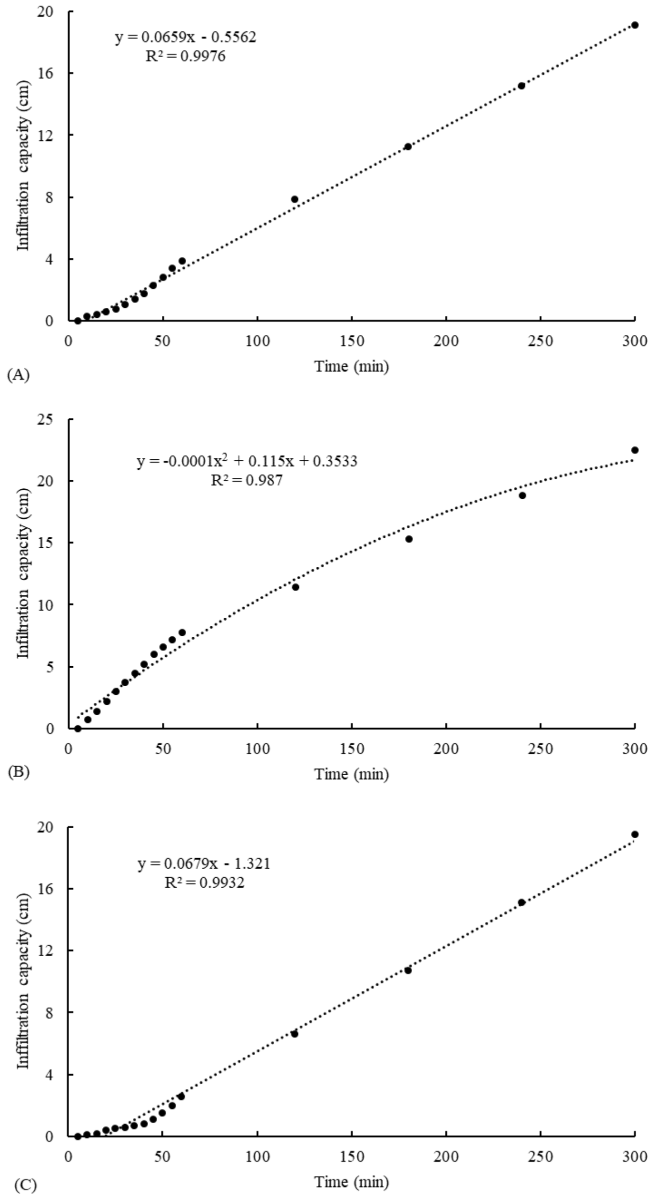

Figure 2: Regression of the water infiltration capacity data as a function of the accumulated time for the treatments T1 – native pasture with grazing (A); T2 – planting on soybean straw (B); T3 – planting on former garlic cultivation (soil plowed and harrowed) (C).

4. CONCLUSIONS

The management kind has induced changes in the physical properties of the soils, especially water retention capacity and the water infiltration speed, with excessive plowing having an overall negative effect on these properties. In this sense, it is recommended to avoid excessive plowing, which may have deleterious effects on the water retention and its infiltration capacity and speed on the affected soils.

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