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ORIGINAL ARTICLE

Vegetation cover arrangements in the recovery of degraded areas in the Brazilian semi-arid region: effect on soil chemical and physical properties

Arranjos de cobertura vegetal na recuperação de áreas degradadas no semiárido: efeito nos atributos químicos e físicos do solo

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Abstract

Soil chemical and physical attributes can be considered one of the main indicators of soil quality and can be useful in monitoring and diagnosing the current condition of a degraded area. The objective of this study was to evaluate the use of herbaceous plants native to the semi-arid region in the recovery of degraded areas through changes in soil chemical and physical attributes in areas altered by the implementation of the São Francisco River Integration Project (SFIP). The experiment was carried out in Cabrobó, Brazil, in the North Axis. The herbaceous plants were sown in an intercropping, totaling 16 treatments (15 densities and the control) distributed in four blocks. Three soil samples were taken and soil chemical and physical attributes were determined. Two statistical analyses were performed, the first one in a randomized block design (RBD) with 16 treatments (densities) and four replications, and the second one, analyzing the sampling times (control, second and third samplings) in the four intercropping blocks. Changes in soil attributes due to area recovery practices were found in the surface layer. Although there was no statistical difference between the cover plants used, there was a temporal change in some chemical attributes, such as SOM, K^+, Mg^{2+}, and P, which showed an increase between the control and the second sampling, in addition to a reduction between the second and third samplings. Thus, the recovery of the soils of areas altered by the SFIP should be carried out continuously until the stabilization of the ecological system.

Keywords: Environmental degradation; *Raphiodon echinus; Senna uniflora; Tridax procumbens*.

Resumo

Os atributos químicos e físicos do solo podem ser considerados um dos principais indicadores de qualidade do solo, podendo ser útil no monitoramento e diagnóstico da condição atual de uma área degradada. O objetivo deste estudo foi avaliar o uso de plantas herbáceas nativas do semiárido na recuperação das áreas degradadas, por meio das alterações nos atributos químicos e físicos do solo em áreas alteradas pela implantação do Projeto de Integração do Rio São Francisco (PISF). O experimento foi desenvolvido no município de Cabrobó-PE, Brasil, no Eixo Norte. As plantas herbáceas foram semeadas em consórcio, totalizando 16 tratamentos (15 densidades e a testemunha) e distribuídas em quatro blocos. Foram realizadas três coletas de solo e determinados os atributos químicos e físicos do solo. Foram realizadas duas análises estatísticas, a primeira em delineamento de blocos casualizados (DBC) com 16 tratamentos (densidades) e quatro repetições, e a segunda analisando as épocas de amostragem (controle, segunda e terceira amostragens) nos quatro blocos consorciados. Alterações nos atributos do solo devido às práticas de recuperação da área foram evidenciadas na camada superficial. Apesar de não ter apresentado diferença estatística entre as plantas de cobertura utilizadas, houve mudança temporal de alguns atributos químicos, como MOS, K^+, Mg^{2+} e P, que demonstraram aumento entre a

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testemunha e a segunda amostragem. Dessa forma, a recuperação dos solos das áreas alteradas pelo PISF deverá ocorrer continuamente até a estabilização do sistema ecológico.

Palavras-chave: Degradação ambiental; *Raphiodon echinus*; *Senna uniflora*; *Tridax procumbens*.

INTRODUCTION

The São Francisco River Integration Project (SFIP) is one of the largest water projects on the planet. The project consists of capturing water in the São Francisco River and adding it to water basins in the northern northeast of Brazil, in the states of Ceará, Paraíba, Pernambuco, and Rio Grande do Norte States. However, along with its execution, it brings an immense environmental degradation in the Brazilian semi-arid region (Roman, 2017). The areas surrounding the channels needed to be changed due to activities such as excavation of the channel and the transfer of materials that were constantly removed, in addition to the transportation of various types of heavy machinery, resulting in a vegetation suppression that hinders recovery activities (Alves et al., 2012), Therefore, the vegetation is necessary to minimize the environmental impacts caused by the project (Alves et al., 2012; Nogueira et al., 2012; Sousa et al., 2018).

The use of native herbaceous plants from the semi-arid region as soil cover is one of the main techniques used in the recovery of degraded land, precisely because those plants have characteristics such as resistance to water stress, low nutrient requirement, seed dispersal effectiveness, quick multiplication, ability to interact with symbiont microorganisms, rusticity and good soil coverage (Mesquita et al., 2018).

Cover plants have long been touted for their ability to reduce erosion, fix atmospheric nitrogen, reduce nitrogen leaching, and improve soil health. One of the great advantages of using plants with good soil coverage capacity is that they act to protect the soil, dissipating the kinetic energy of raindrops, thus contributing to prevent the erosion process. Because of that, cover plants reduced vulnerability to erosion from extreme rain events, increased soil water management options during droughts or periods of soil saturation, and retention of nitrogen mineralized due to warming (Kaye & Quemada, 2017). In addition, cover plants help improve soil chemical and physical properties through their root system, causing direct effects on soil macro and micro-porosity, bulk density, and soil water infiltration (Muñoz-Rojas et al., 2016). The ideal density of plants also favors nutrient cycling, which increases their availability to plants, especially those species able to create a symbiosis with microorganisms (Bressan et al., 2013).

Soil chemical and physical properties are the main indicators in monitoring and diagnosing the current condition of the degraded land, providing essential information for decision-making of recovery activities (Pezarico et al., 2013). This is because soil properties are directly related to the processes and aspects of their variation in time and space, so any change will affect fertility, biological activity and structure of the soil, which can cause serious damage both to soil and to the ecosystem (Tarrasón et al., 2016).

The hypothesis of this study is that cover plants will affect positively the soil properties, helping in the recovery of areas degraded by the SFIP. Therefore, the objective of this study was to evaluate the use of Brazilian semi-arid native herbaceous species for the recovery of degraded lands, observing changes in soil chemical and physical properties in areas modified by the execution of the SFIP.

MATERIAL AND METHODS

Site description

The experiment started in March 2016 and continued until June 2017 and it was carried out in the municipality of Cabrobó, Pernambuco state, Brazil, in the catchment areas of the São Francisco River Integration Project (SFIP) channel, on the north axis, between the coordinates 08°26'52.6” S and 39°24'54” W and at 366 m asl. According to Köppen's classification, the local climate is BSh, which is semi-arid, with annual precipitation of 561.3 mm concentrated in the summer and annual mean temperature varying from 20.8 °C to 33.4 °C and annual mean relative humidity of 60%. The climatic data related to the experimental period are shown in Figure 1.

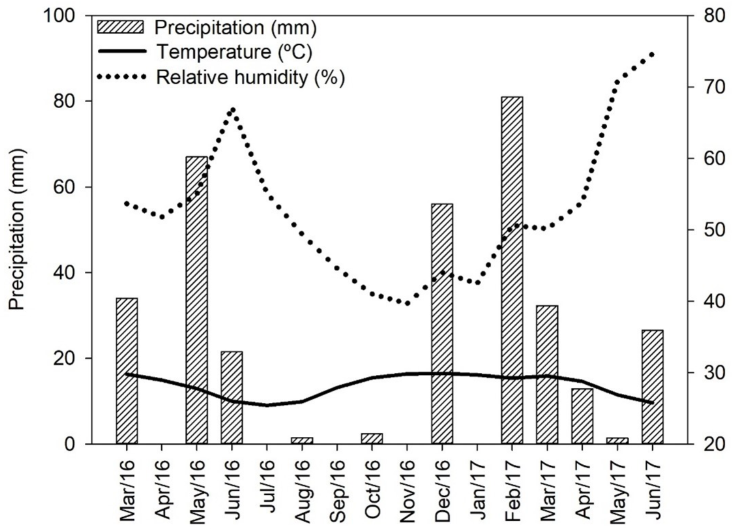

Figure 1. Monthly data of precipitation, air temperature, and average relative humidity during the experimental period.

The area selected for the experiment had no soil cover, so it was exposed, unstructured, with compacted soil, and without any plants. The soil around the northern axis channel was originally classified as Chromic Luvisol, very stony in the superficial layers, shallow, with eutrophic character and sandy loam texture (Carvalho et al., 2022). However, it is important to highlight that due to excavation operations, material transport and heavy machinery traffic in some parts of the experiment, the area was so modified by the SFIP that the soil lost some of their initial and natural characteristics (diagnostic horizons, depth etc.). In terms of soil texture, the mean values of the entire degraded area surrounding the catchment of the northern axis consisted of 684 g kg^{-1} sand, 159 g kg^{-1} silt, and 157 g kg^{-1} clay.

The experiment was carried out in a randomized block design with four replications, the treatments were 15 plant densities and the control treatment consisted of the soil sampling that was performed before the experiment started (without plants) (Table 1). Each block had an area of 304 m^2, and each treatment plot was 5.0 m long and 2.0 m wide, totaling 10 m^2, with 1.0 m spacing between plots and 0.25 m border.

Table 1. Plant density of the evaluated treatments and the number of individuals per species within each plot

Density	**T 1.1**	**T 1.2**	**T 1.3**	**T 1.4**	**T 1.5**
S. uniflora (100%)	20	36	48	64	80
R. echinus (0%)	0	0	0	0	0
T. procubens (0%)	0	0	0	0	0
Total	20 plants	36 plants	48 plants	64 plants	80 plants
Density	T 2.1	T 2.2	T 2.3	T 2.4	T 2.5
S. uniflora (70%)	20	36	48	64	80
R. echinus (15%)	4	8	11	14	17
T. procubens (15%)	4	8	11	14	17
Total	28 plants	52 plants	70 plants	92 plants	114 plants
Density	T 3.1	T 3.2	T 3.3	T 3.4	T 3.5
S. uniflora (50%)	20	36	48	64	80
R. echinus (25%)	10	18	25	33	40
T. procubens (25%)	10	18	25	33	40
Total	40 plants	72 plants	96 plants	130 plants	160 plants

The sowing of the three species of herbaceous plants (*Senna uniflora*, *Rhaphiodon echinus*, and *Tridax procubens*) was carried out manually in rows, with different spacings and densities in March 2016 (Table 1). The soil tillage of the experiment was carried out with a 75-hp-tractor equipped with a disc plow in order to superficially till the soil (10 cm). Considering the very small dimensions of the seeds, the effective sowing depth was standardized, considering only the first centimeters of the soil profile, not exceeding 8 cm in depth. For this purpose, small gardening shovels were used to open the superficial holes. Five seeds of *Senna uniflora* and *Rhaphiodon echinus* were used for each planting point within the plots. Due to the tiny and anemochoric seed of *Tridax procubens* a 50 mL plastic recipient filled with seeds was used for each planting point within the plots.

Due to the low rainfall recorded at the beginning of the experimental period in the months of March and April (Figure 1), it was necessary to complement the water availability through irrigation so that the seeds could germinate. Since in 2016 the rainfall in the region was very low, especially in the rainy season, manual irrigation was carried out five times a week in order to favor germination and initial development. An irrigation depth of approximately 3.28 mm was used during the months of March, April, May, and mid-June.

The degraded area recovery arrangement

The proposed recovery arrangement was defined based on a previous study carried out and published by Carvalho et al. (2020) and Carvalho et al. (2022) on the two axes of the transposition channels, aiming to prospect pioneer herbaceous species of the native flora of the Caatinga biome with potential for vegetation cover in degraded lands. For this, a floristic survey was carried out as well as a coverage and density survey of the herbaceous layer (Carvalho et al., 2022). Based on this information, Carvalho et al. (2022) created attributes to select the species, which were: origin, habit, life cycle, propagation, dispersal syndrome, coverage, density, and allelopathic effects. Each attribute had its respective weight for a score according to its degree of importance for soil cover and recovery of degraded areas.

Due to the capacity for soil coverage, *Senna uniflora*, *Tridax procumbens,* and *Raphiodon echinus* showed a potential to recover degraded lands under semi-arid conditions. All evaluated densities can be found in Table 1.

Soil sampling

Disturbed soil samples were collected in the 0-20 cm and 20-40 cm layers and undisturbed (5 cm x 5 cm) soil samples were collected only in the superficial layer. In each plot, five individual soil samples were collected to compose a composite sample in each layer (0-20 cm and 20-40 cm). For the undisturbed samples, one volumetric cylinder was collected for each plot. Therefore, 120 disturbed and 60 undisturbed soil samples were obtained in each sampling.

The first soil sampling was carried out before the implementation of the experiment in March 2016, which was used as the control treatment. In November 2016, a second soil sampling was carried out, just after the end of the plant cycle, which occurred after the driest period of the year in the region (August to November). The information in this soil sampling refers to the first generation of herbaceous plants that were sown manually.

The third soil sampling was carried out in June 2017, after the rainy season, which according to climatological data goes from mid-December to May. The information obtained after this soil sampling was related to the time after the rainy season and the second generation of herbaceous plants, which appeared spontaneously originating from the first plants.

Soil analyses

The chemical analyses followed the methodologies proposed by Teixeira et al. (2017), in which the pH was determined in water (1:2.5), electrical conductivity (EC) through the saturated paste method, and soil organic matter content (SOM) using oxidation to CO_2 by dichromate ions in strongly acidic medium. Phosphorus content (P) was determined by visible ultraviolet (UV) spectrometry, sodium content (Na^+) and potassium content (K^+) were extracted using the Mehlich-1 method and the reading was performed by flame emission photometry. Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) were extracted with 1.0 mol L^{-1} KCl solution and the reading was carried out through atomic absorption spectrometry. Potential acidity (H + Al) was obtained from extraction with calcium acetate and alkalimetry titration of the extract. From the analyses, the sum of bases (SB), base saturation (V), cation exchange capacity (CEC), and the percentage of sodium saturation (PSS) were calculated.

In samples classified as saline soil (EC > 4.0 dS m^{-1}) according to Richards' classification (Richards, 1954a), the exchangeable cations and P content were determined following methodologies described by Olsen et al. (1954) and Thomas (1982). P content was extracted in a sodium bicarbonate solution and determined using visible ultraviolet spectrometry (Olsen et al., 1954). The samples were washed with 92.8º alcohol, and Ca^{2+}, Mg^{2+}, K^+, and Na^+ contents were extracted with a 1.0 mol L^{-1} ammonium acetate solution (Thomas, 1982). Na^+ and K^+ were determined by flame emission photometry, and Ca^{2+} and Mg^{2+} by atomic absorption spectrometry (Richards, 1954b).

Physical analyses were soil texture by the pipette method, soil bulk density (Bd), and total porosity (TP) by the gravimetric oven method proposed by Teixeira et al. (2017). Macro (Ma) and micro porosity (Mi) were estimated using a mathematical model proposed by Stolf et al. (2011), using Bd and sand content data.

Statistics analyses

The data were tested for normality of the residuals (Shapiro-Wilk) and the homogeneity of variance (Bartlett). Transformations were performed when the variable did not show normal distribution. The variables were subjected to analysis of variance, and the Scott-Knott test at 5% probability level was used to compare the means.

In order to temporarily assess changes in soil properties after the management of the area (fertilization, plowing, use of herbaceous plants), a comparison was made between changes in the initial state of the area (control or first soil sampling) and the two soil samplings (second and third soil samplings). For this analysis, each soil sampling was considered as a treatment, and each block as a replication. Thus, this second analysis was carried out considering an experiment in a completely randomized design with three treatments (control, second soil sampling and third soil sampling) and four replications (the means of the different intercropping blocks). Student's t-test at 5% probability level was used to compare the means. All statistical analyses were performed using R software version 3.2.5 (R Core Team, 2016).

RESULTS AND DISCUSSION

Second soil sampling results

In the second soil sampling (November 2016), just after the end of the cycle of herbaceous plants, in the 0-20 cm layer, soil pH did not show a statistical difference and the mean values varied from 6.7 to 7.2. Electrical conductivity (EC) was considered high, varying from 1.8 to 5.2 dS m^{-1}, which shows the presence of soluble salts in the areas altered by the São Francisco River Integration Project (SFIP). However, the EC mean values did not show a statistical difference between the treatments (Table 2).

Table 2. Mean values of the soil chemical properties in the second soil sampling in the 0-20 cm layer, after the cultivation of herbaceous plants in the areas modified by the São Francisco River Integration Project.

Treat	pH	EC	SOM	Na^+	K^+	Mg^{2+}	Ca^{2+}	SB	CEC	PSS	P
	H_2O	dS m^{-1}	g kg^{-1}	------------------------------------cmol$_c$ dm^{-3}------------------------------------						%	mg dm^{-3}
1.1	6.9^{ns}	1.8^{ns}	16.8 a	1.8^{ns}	0.8 a	6.8 b	4.4^{ns}	13.7 b	13.7 b	12.7^{ns}	37.7 a
1.2	6.9	4.0	14.4 a	1.5	0.8 a	34.5 a	3.2	40.0 a	40.0 a	13.6	56.5 a
1.3	6.7	2.4	15.9 a	2.3	0.9 a	7.8 b	4.2	15.3 b	15.3 b	15.3	27.5 a
1.4	6.8	2.8	15.6 a	2.0	1.0 a	9.8 b	4.5	17.2 b	17.3 b	11.5	31.5 a
1.5	6.8	2.2	15.3 a	3.1	1.8 a	8.4 b	5.0	18.2 b	18.3 b	16.7	72.6 a
2.1	7.0	2.1	14.8 a	4.5	1.1 a	8.9 b	3.6	18.1 b	18.1 b	24.8	51.1 a
2.2	6.9	2.8	14.3 a	4.4	0.7 a	12.8 b	4.1	22.0 b	22.0 b	20.2	42.9 a
2.3	6.9	2.6	14.8 a	6.3	0.9 a	11.8 b	2.7	21.6 b	21.7 b	29.0	56.9 a
2.4	6.9	3.0	11.5 a	5.2	0.8 a	12.2 b	3.1	21.3 b	21.3 b	24.4	14.4 b
2.5	6.9	2.3	11.1 a	6.9	1.0 a	10.0 b	5.1	22.9 b	22.9 b	30.1	46.6 a
3.1	7.0	2.2	12.0 a	3.9	0.8 a	8.1 b	4.3	17.1 b	17.1 b	22.6	58.6 a
3.2	6.9	2.8	13.2 a	2.6	0.8 a	11.0 b	2.0	16.4 b	16.4 b	15.6	45.4 a
3.3	6.9	4.9	12.5 a	2.8	0.8 a	10.9 b	3.3	17.9 b	18.0 b	15.8	37.0 a
3.4	6.7	2.8	13.7 a	2.6	0.9 a	10.5 b	3.1	17.0 b	17.0 b	15.0	28.1 b
3.5	6.9	5.2	13.3 a	2.3	0.9 a	9.4 b	3.3	15.8 b	15.8 b	14.2	24.3 b
Test	7.2	3.0	6.5 b	1.8	0.2 b	3.4 c	3.6	9.0 c	9.0 c	19.8	5.8 c
CV (%)	5.9	6.6	15.1	53.7	13.2	36.5	36.5	15.2	15.1	43.8	33.7

*Mean values followed by different letters in the columns differ statistically at the level of 5% probability according to the Scott-Knott test; ns= not significant. electrical conductivity (EC); soil organic matter (SOM); sum of basis (SB); cation exchange capacity (CEC); percentage of sodium saturation (PSS). Treatment 100% *S. uniflora*: 1.1, 20 plants; 1.2, 36 plants; 1.3, 48 plants; 1.4, 64 plants; 1.5, 80 plants. Treatment 70% *S. uniflora*, 15% *R. echinus* and 15% *T. procumbens*: 2.1, 28 plants; 2.2, 52 plants; 2.3, 70 plants; 2.4, 92 plants; 2.5, 114 plants. Treatment 50% *S. uniflora*, 25% *R. echinus* and 25% *T. procumbens*: 3.1, 40 plants; 3.2, 72 plants; 3.3, 96 plants; 3.4, 130 plants; 3.5, 160 plants and control (initial condition without plants). CV = coefficient of variation. Treat = Treatment.

All plant densities evaluated led to higher soil organic matter (SOM) contents than the initial soil condition (6.5 g kg^{-1}). Among the plant density treatments there was no statistical difference and the SOM contents ranged from 11.1 to 16.8 g kg^{-1} (Table 2).

Na^+ content was high since the percentage of sodium saturation (PSS) in most of the treatments was higher than 15% (Santos et al., 2018). However, there was no statistical difference between the treatments. Similarly, Ca^{2+} content did not show a statistical difference between the treatments and its values varied from 2.0 to 5.1 cmol$_c$ dm^{-3} (Table 2).

There were significant statistical differences for K^+ and Mg^{2+} contents, and both variables showed values greater than those found in the control treatment. For K^+, the control treatment showed a value of 0.2 cmol$_c$ dm^{-3}, whereas the values of the other treatments varied from 0.7 to 1.8 cmol$_c$ dm^{-3}. The initial value of Mg^{2+} content was 3.4 cmol$_c$ dm^{-3}, while all other treatments were statistically superior, especially the treatment 1.2, which showed a value of 34.5 cmol$_c$ dm^{-3}, higher than those of the other treatments. Due to the high Mg^{2+} content and the low values of potential acidity (H + Al) in the intercropping blocks, the variables sum of basis (SB) and cation exchange capacity (CEC) showed similar results to those found for Mg^{2+} (Table 2).

The soil P content in the treatments 2.4, 3.4, and 3.5 showed lower values than at the other densities (14.4; 28.1 and 24.3 mg dm^{-3}, respectively). However, all plant densities were better than the control, which showed a value of 5.8 mg dm^{-3} (Table 2).

The results of the soil chemical properties in the 20-40 cm layer were similar to those found in the topsoil layer (Table 3). The pH values varied from 6.6 to 7.8 and EC from 1.5 and 4.9 dS m^{-1}, but no statistical differences were found for both variables. A result similar to that found in the topsoil layer was also found for the SOM content, where all treatments were superior to the control treatment (5.6 g kg^{-1}).

Table 3. Mean values of the soil chemical properties in the second soil sampling, in the 20-40 cm layer, after the cultivation of herbaceous plants in the areas modified by the São Francisco River Integration Project.

Treat	pH	EC	SOM	Na^+	K^+	Mg^{2+}	Ca^{2+}	SB	CEC	PSS	P
	H_2O	dS m^{-1}	g kg^{-1}	---------------	---------------	---------------	$cmol_c$ dm^{-3}	---------------	---------------	%	mg dm^{-3}
1.1	7.0^{ns}	2.4^{ns}	17.3 a	3.3^{ns}	0.8 a	10.9^{ns}	4.1^{ns}	19.2^{ns}	19.2^{ns}	16.5^{ns}	35.7^{ns}
1.2	7.1	3.7	14.4 a	3.5	0.5 a	9.8	3.4	17.0	17.0	23.0	31.3
1.3	6.8	3.6	14.9 a	3.0	0.6 a	5.8	3.5	12.8	12.9	26.1	41.2
1.4	7.8	1.5	16.2 a	1.9	0.7 a	4.8	4.6	12.0	12.0	15.5	30.7
1.5	7.1	4.0	16.1 a	3.4	0.6 a	10.7	3.8	18.5	18.6	20.9	18.4
2.1	7.1	3.8	14.9 a	3.2	0.7 a	10.7	3.5	18.0	18.1	20.9	29.4
2.2	7.1	4.6	15.6 a	3.5	0.7 a	10.5	3.7	18.4	18.5	21.5	19.3
2.3	6.6	4.5	12.5 a	3.2	0.4 a	6.6	1.6	11.8	12.0	24.1	28.8
2.4	7.1	3.8	12.5 a	3.6	0.6 a	9.0	4.3	17.4	17.4	23.5	14.7
2.5	7.0	3.7	12.2 a	3.9	0.6 a	8.2	3.8	16.5	16.6	31.2	36.0
3.1	7.2	2.9	13.1 a	3.5	0.7 a	6.3	4.4	14.9	14.9	28.2	37.9
3.2	6.7	4.6	13.4 a	2.9	0.4 a	7.7	3.0	14.0	14.1	21.0	22.8
3.3	7.0	3.9	12.7 a	3.9	0.6 a	6.5	2.9	13.9	13.9	31.3	48.2
3.4	6.7	4.6	13.7 a	4.5	0.5 a	7.0	3.4	15.4	15.5	33.9	19.9
3.5	7.1	4.9	13.3 a	3.9	0.6 a	6.3	3.5	14.2	14.3	24.5	17.9
Test	7.0	3.4	5.6 b	1.6	0.2 b	3.6	4.2	9.7	10.7	14.1	21.8
CV (%)	6.9	29.8	36.4	49.48	14.6	53.4	39.5	29.5	29.0	56.4	31.5

*Mean values followed by different letters in the columns differ statistically at the level of 5% probability according to the Scott-Knott test; ns= not significant. electrical conductivity (EC); soil organic matter (SOM); sum of basis (SB); cation exchange capacity (CEC); percentage of sodium saturation (PSS). Treatment 100% *S. uniflora*: 1.1, 20 plants; 1.2, 36 plants; 1.3, 48 plants; 1.4, 64 plants; 1.5, 80 plants. Treatment 70% *S. uniflora*, 15% *R. echinus* and 15% *T. procumbens*: 2.1, 28 plants; 2.2, 52 plants; 2.3, 70 plants; 2.4, 92 plants; 2.5, 114 plants. Treatment 50% *S. uniflora*, 25% *R. echinus* and 25% *T. procumbens*: 3.1, 40 plants; 3.2, 72 plants; 3.3, 96 plants; 3.4, 130 plants; 3.5, 160 plants and control (initial condition without plants). CV = coefficient of variation. Treat = Treatment.

The Na^+ content was also high in the subsurface layer, and the PSS values found in the intercropping blocks varied from 14.1 to 33.9%. However, there was no statistical difference between treatments. Ca^{2+} and Mg^{2+} contents also showed no statistical difference. Consequently, SB and CEC also did not differ statistically (Table 3).

Among the exchangeable cations, only K^+ content showed a statistical difference in the 20-40 cm layer, in which the plant density treatments were superior to the control treatment (0.2 $cmol_c$ dm^{-3}). In this same layer, there was also no statistical difference in P content (Table 3).

The soil physical properties in the 0-20 cm layer: soil bulk density (BD), total porosity (TP), macroporosity (Ma) and microporosity (Mi) were not statistically different in the evaluated treatments (Table 4).

Table 4. Mean values of the soil physical properties in the second soil sampling in the superficial layer, after the cultivation of herbaceous plants in the areas modified by the São Francisco River Integration Project.

Treat	BD	TP	Ma	Mi
	g cm^{-3}	------------	%	------------
1.1	1.53 ns	37.21 ns	12.7 ns	24.52 ns
1.2	1.46	37.9	16.2	21.8
1.3	1.60	35.5	9.7	25.8
1.4	1.45	40.2	17.9	22.3
1.5	1.48	42.0	14.8	27.2
2.1	1.42	40.2	18.0	22.2
2.2	1.55	36.4	12.0	24.4
2.3	1.46	41.3	15.9	25.4
2.4	1.48	39.1	15.0	24.1
2.5	1.50	38.6	14.3	24.3
3.1	1.47	40.6	13.1	27.5

Table 4. Continued...

Treat	BD	TP	Ma	Mi
	g cm^{-3}	------------%------------		
3.2	1.52	38.7	12.7	25.9
3.3	1.61	32.6	8.8	23.8
3.4	1.59	32.9	9.7	23.2
3.5	1.53	35.5	13.7	21.8
Test	1.55	39.6	12.8	26.7
CV(%)	6.6	14.3	34.0	16.2

*Mean values followed by different letters in the columns differ statistically at the level of 5% probability according to the Scott-Knott test; ns= not significant. Bulk density (BD); total porosity (TP); macroporosity (Ma); microporosity (Mi). Treatment 100% *S. uniflora*: 1.1, 20 plants; 1.2, 36 plants; 1.3, 48 plants; 1.4, 64 plants; 1.5, 80 plants. Treatment 70% *S. uniflora*, 15% *R. echinus* and 15% *T. procumbens*: 2.1, 28 plants; 2.2, 52 plants; 2.3, 70 plants; 2.4, 92 plants; 2.5, 114 plants. Treatment 50% *S. uniflora*, 25% *R. echinus* and 25% *T. procumbens*: 3.1, 40 plants; 3.2, 72 plants; 3.3, 96 plants; 3.4, 130 plants; 3.5, 160 plants and control (initial condition without plants). CV = coefficient of variation. Treat = Treatment. BD varied from 1.45 and 1.61 g cm^{-3}, and TP varied from 32.6 to 42%. Mi varied from 21.8 to 27.5% and Ma varied from 8.8 to 18%.

Third soil sampling results

The results obtained in the third soil sampling (June 2017) were similar to those found in the second soil sampling (November 2016). The pH values remained close to neutrality, varying from 6.7 to 7.2, with no statistical difference between the treatments. The results of the EC values were similar to those found in the second soil sampling, showing an excessive presence of soluble salts in the soil, with mean values reaching up to 4.9 dS m^{-1} (Table 5).

SOM did not show a statistical difference between the treatments evaluated (Table 5). This result was different from those found in the second soil sampling, in which the plant density treatments increased SOM compared to the control (Table 3).

Regarding exchangeable cations, only Mg^{2+} content showed a statistical difference, in which all plant densities evaluated were better than the control treatment. However, treatments 1.1, 1.2, 1.3, 1.4, 1.5, 2.1, 2.2, 2.3, 2.4, 2.5, 3.1 and 3.2 were superior to treatments 3.3, 3.4 and 3.5 (Table 5).

Table 5. Mean values of the soil chemical properties in the third soil sampling, in the 0-20 cm layer, after the cultivation of herbaceous plants in the areas modified by the São Francisco River Integration Project.

Treat	pH	EC	SOM	Na^+	K^+	Mg^{2+}	Ca^{2+}	SB	CEC	PSS	P
	H_2O	dS m^{-1}	g kg^{-1}	------------cmol$_c$ dm^{-3}------------						%	mg dm^{-3}
1.1	7.2^{ns}	0.7^{ns}	8.6^{ns}	1.4^{ns}	0.2^{ns}	13.2 a	8.0^{ns}	22.8 a	22.8 a	6.1^{ns}	36.8 a
1.2	7.2	1.4	7.6	3.2	0.2	15.7 a	5.6	24.7 a	24.7 a	12.9	50.5 a
1.3	6.7	2.1	11.7	1.1	0.2	11.8 a	6.4	19.6 a	19.6 a	5.7	35.2 a
1.4	7.0	1.8	9.2	2.3	0.2	12.9 a	5.2	20.7 a	20.7 a	11.2	27.5 a
1.5	7.0	3.8	7.2	1.3	0.2	11.6 a	5.3	18.4 a	18.4 a	6.9	51.5 a
2.1	7.0	3.4	7.7	1.7	0.2	9.0 a	5.9	16.8 a	16.8 a	10.4	32.8 a
2.2	7.0	2.5	7.7	1.2	0.2	9.6 a	5.6	16.6 a	16.7 a	7.2	38.9 a
2.3	6.8	2.8	8.1	2.4	0.2	10.6 a	5.6	18.9 a	18.9 a	12.9	65.0 a
2.4	7.1	2.7	7.1	1.5	0.2	10.1 a	5.7	17.5 a	17.5 a	8.4	39.3 a
2.5	6.7	3.4	6.8	1.9	0.2	9.4 a	6.0	17.4 a	17.4 a	10.7	46.7 a
3.1	7.1	3.0	6.4	1.3	0.2	10.1 a	6.5	18.1 a	18.1 a	7.2	28.2 a
3.2	6.9	4.3	7.8	1.8	0.2	10.3 a	6.4	18.7 a	18.7 a	9.8	49.4 a
3.3	6.7	4.9	7.3	1.3	0.2	7.4 b	5.6	14.5 a	14.5 a	9.2	62.4 a
3.4	6.7	2.1	7.6	1.2	0.2	8.4 b	5.5	15.4 a	15.4 a	7.8	36.4 a
3.5	7.2	4.1	6.6	2.3	0.2	7.2 b	6.3	16.0 a	16.1 a	14.4	30.7 a
Test	7.2	3.0	6.5	1.8	0.2	3.4 c	3.6	9.0 b	9.0 b	19.8	5.8 b
CV (%)	4.6	48.5	15.9	33.6	10.2	24.0	22.0	8.4	8.3	32.7	28.1

*Mean values followed by different letters in the columns differ statistically at the level of 5% probability according to the Scott-Knott test; ns= not significant. electrical conductivity (EC); soil organic matter (SOM); sum of basis (SB); cation exchange capacity (CEC); percentage of sodium saturation (PSS). Treatment 100% *S. uniflora*: 1.1, 20 plants; 1.2, 36 plants; 1.3, 48 plants; 1.4, 64 plants; 1.5, 80 plants. Treatment 70% *S. uniflora*, 15% *R. echinus* and 15% *T. procumbens*: 2.1, 28 plants; 2.2, 52 plants; 2.3, 70 plants; 2.4, 92 plants; 2.5, 114 plants. Treatment 50% *S. uniflora*, 25% *R. echinus* and 25% *T. procumbens*: 3.1, 40 plants; 3.2, 72 plants; 3.3, 96 plants; 3.4, 130 plants; 3.5, 160 plants and control (initial condition without plants). CV = coefficient of variation. Treat = Treatment.

For Ca^{2+} content, the values were similar to those found in the second soil sampling. There was a decrease in the Na^+, PSS, and K^+ values compared to the second soil sampling. However, SB, CEC, and P content showed a statistical difference between plant densities treatments and the control (Table 5).

In the 20-40 cm layer, pH values were similar to those found in the second soil sampling and varied from 6.7 to 7.2. The EC values remained high, but there was no statistical difference between the treatments. The SOM content also did not differ statistically, similar to topsoil (Table 6). In addition, SB and CEC also showed no statistical difference.

Table 6. Mean values of the soil chemical properties in the third soil sampling, in the 20-40 cm layer, after the cultivation of herbaceous plants in the areas modified by the São Francisco River Integration Project.

Treat	pH	EC	SOM	Na^+	K^+	Mg^{2+}	Ca^{2+}	SB	CEC	PSS	P
	H_2O	dS m^{-1}	g kg^{-1}	----------	----------	----------	cmol$_c$ dm^{-3}	----------	----------	%	mg dm^{-3}
1.1	7.1^{ns}	2.4^{ns}	12.5^{ns}	1.8^{ns}	0.3^{ns}	10.0 a	6.0^{ns}	18.1^{ns}	18.1^{ns}	7.9^{ns}	103.5 a
1.2	7.1	3.5	9.2	2.5	0.2	9.4 a	5.6	17.8	17.8	12.8	81.8 a
1.3	7.1	2.7	10.1	1.9	0.2	11.3 a	6.4	19.8	19.8	8.0	48.4 a
1.4	7.2	1.4	7.9	2.5	0.2	13.7 a	5.4	21.8	21.8	10.3	26.2 a
1.5	7.1	5.9	7.7	2.1	0.2	10.7 a	6.0	18.9	18.9	9.9	26.9 a
2.1	7.1	5.4	7.6	2.0	0.1	8.8 a	6.3	17.3	17.3	9.9	39.0 a
2.2	7.0	2.3	8.4	2.0	0.2	11.4 a	6.5	20.1	20.1	9.0	37.8 a
2.3	6.8	4.7	8.4	2.0	0.1	8.2 a	5.8	16.1	16.1	11.5	35.4 a
2.4	6.8	4.6	8.9	1.3	0.1	6.0 a	5.3	12.8	12.8	9.4	38.7 a
2.5	6.6	4.6	8.2	1.8	0.1	8.9 a	7.0	17.9	17.9	10.2	30.8 a
3.1	6.9	4.4	7.1	2.0	0.2	10.3 a	6.6	18.9	19.0	10.3	38.6 a
3.2	7.2	6.4	9.0	1.9	0.1	7.7 a	6.0	15.7	15.7	10.7	35.3 a
3.3	7.0	2.4	7.9	2.1	0.2	9.3 a	5.4	17.0	17.0	11.0	41.7 a
3.4	6.7	4.9	7.0	1.8	0.2	7.0 a	6.2	15.2	15.2	13.7	39.3 a
3.5	7.1	5.5	8.2	2.4	0.3	5.6 a	6.1	14.3	14.3	14.1	32.5 a
Test	7.0	3.4	5.6	1.6	0.2	3.6 b	4.2	9.7	10.3	14.6	21.8 b
CV (%)	5.5	33.7	33.1	53.1	16.3	40.7	26.2	26.5	26.6	53.6	17.8

*Mean values followed by different letters in the columns differ statistically at the level of 5% probability according to the Scott-Knott test; ns= not significant. electrical conductivity (EC); soil organic matter (SOM); sum of basis (SB); cation exchange capacity (CEC); percentage of sodium saturation (PSS). Treatment 100% *S. uniflora*: 1.1, 20 plants; 1.2, 36 plants; 1.3, 48 plants; 1.4, 64 plants; 1.5, 80 plants. Treatment 70% *S. uniflora*, 15% *R. echinus* and 15% *T. procumbens*: 2.1, 28 plants; 2.2, 52 plants; 2.3, 70 plants; 2.4, 92 plants; 2.5, 114 plants. Treatment 50% *S. uniflora*, 25% *R. echinus* and 25% *T. procumbens*: 3.1, 40 plants; 3.2, 72 plants; 3.3, 96 plants; 3.4, 130 plants; 3.5, 160 plants and control (initial condition without plants). CV = coefficient of variation. Treat = Treatment.

Exchangeable cations Na^+, K^+, and Ca^{2+} did not differ statistically between the treatments evaluated, as well as PSS, which was similar to the value found in the topsoil layer. Conversely, Mg^{2+} content showed a statistical difference between the plant densities treatments and the control treatment (3.6 cmol$_c$ dm^{-3}) (Table 6). For P content, the values of treatments that used herbaceous plants were superior to those found in the control (21.8 mg dm^{-3}) (Table 6).

The physical properties of the soil did not show a statistical difference between the treatments (Table 7). The Bd, TP, Ma, and Mi mean values were similar to those found in the second soil sampling. None of the Bd means reached the limit density of 1.59 g cm^{-3} (Stolf et al., 2011) for the evaluated soil texture. Bd means ranged from 1.37 to 1.56 g cm^{-3}. TP means varied from 35.3 to 41.6%, Ma values varied from 11.49 to 20.21% and Mi ranged from 18.16 to 26.76%.

Table 7. Mean values of the soil physical properties in the third soil sampling in the superficial layer, after the cultivation of herbaceous plants in the areas modified by the São Francisco River Integration Project.

Treat	BD	TP	Ma	Mi
	g cm^{-3}	%		
1.1	1.51 ns	38.30 ns	13.77 ns	24.53 ns
1.2	1.44	35.30	17.15	18.16
1.3	1.56	35.36	11.49	23.88
1.4	1.53	36.13	14.13	22.00
1.5	1.45	36.77	16.50	20.28
2.1	1.45	39.76	16.75	23.01
2.2	1.52	36.99	13.37	23.62
2.3	1.47	36.34	15.20	21.14
2.4	1.37	41.60	20.21	21.39
2.5	1.46	41.11	16.16	24.95
3.1	1.49	38.87	12.11	26.76
3.2	1.53	35.67	12.31	23.36
3.3	1.45	37.69	15.97	21.72
3.4	1.50	37.31	13.98	23.32
3.5	1.48	37.17	15.80	21.37
Test	1.55	39.58	12.83	26.74
CV(%)	5.9	9.8	31.0	16.03

*Mean values followed by different letters in the columns differ statistically at the level of 5% probability according to the Scott-Knott test; ns= not significant. Bulk density (BD); total porosity (TP); macroporosity (Ma); microporosity (Mi). Treatment 100% *S. uniflora*: 1.1, 20 plants; 1.2, 36 plants; 1.3, 48 plants; 1.4, 64 plants; 1.5, 80 plants. Treatment 70% *S. uniflora*, 15% *R. echinus* and 15% *T. procumbens*: 2.1, 28 plants; 2.2, 52 plants; 2.3, 70 plants; 2.4, 92 plants; 2.5, 114 plants. Treatment 50% *S. uniflora*, 25% *R. echinus* and 25% *T. procumbens*: 3.1, 40 plants; 3.2, 72 plants; 3.3, 96 plants; 3.4, 130 plants; 3.5, 160 plants and control (initial condition without plants). CV = coefficient of variation. Treat = Treatment.

Temporal changes in soil properties after the use of herbaceous plants

Higher SOM content (14.7 g kg^{-1}) was observed in the second soil sampling in the 0-20 cm layer (Figure 2), and it was statistically superior to the control (5.28 g kg^{-1}). The SOM content in third soil sampling was statistically similar to those found in the control and also in the second soil sampling, with a content of 7.8 g kg^{-1} (Figure 2).

Another variable that was significantly influenced by the soil samplings was the K^+ content; in the second soil sampling, in the 0-20 cm layer, it reached a value of 0.92 cmol$_c$ dm^{-3}. From then on, after irrigation ceased and without new fertilization, the content returned to the initial state of the control, around 0.2 cmol$_c$ dm^{-3} in the third soil sampling (Figure 2). The results of Mg^{2+} content showed that the mean values were similar in the second (11.5 cmol$_c$ dm^{-3}) and third (10.5 cmol$_c$ dm^{-3}) soil samplings, and both means were statistically superior to the initial condition (3.32 cmol$_c$ dm^{-3}) (Figure 2).

The CEC mean value in the initial condition (control), in the 0-20 cm layer, was 9.11 cmol$_c$ dm^{-3}. In the second soil sampling, there was a significant increase in the cation exchange capacity (19.76 cmol$_c$ dm^{-3}), which was statistically similar to the 18.24 cmol$_c$ dm^{-3} found in the third soil sampling (Figure 2). The P content in the topsoil layer in the first sampling (control) was much lower (2.7 mg dm^{-3}) than that found in the second and third samplings. In the third soil sampling, the P content decreased (21.39 mg dm^{-3}). Its mean value, however, was not statistically different from that found in the second soil sampling (34.63 mg dm^{-3}) (Figure 2).

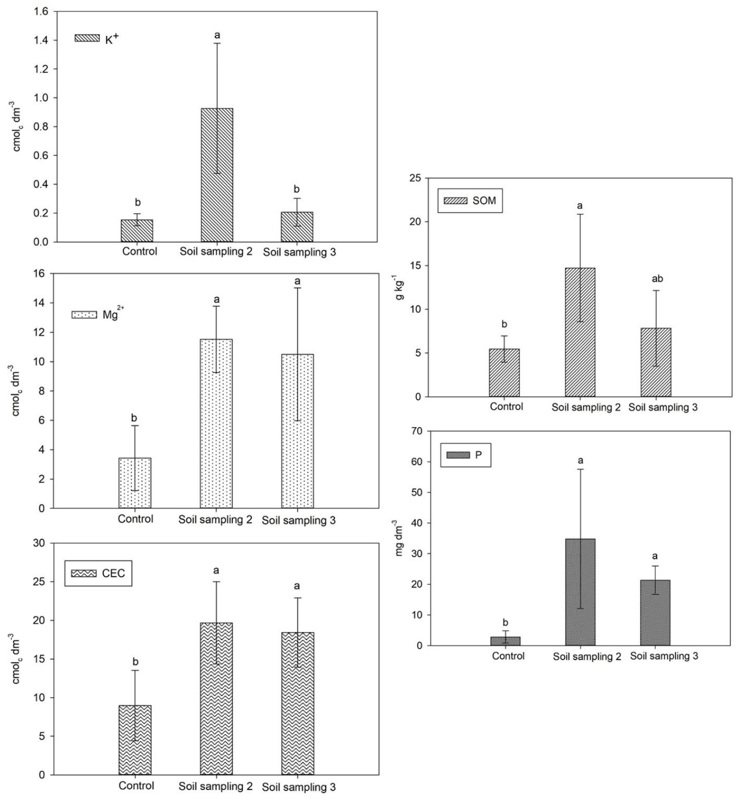

Figure 2. Means and standard deviation of the K^+, Mg^{2+}, P, soil organic matter (SOM) contents and cation exchange capacity (CEC) values in the three soil samplings of the experiment, in the 0-20 cm layer, on the north axis of the São Francisco River Integration Project. Control, initial condition (March 2016); soil sampling 2, the first generation of the cover plants (November 2016); soil sampling 3, the second generation of the cover plants (June 2017). Means followed by different letters differ statistically at the 5% probability level according to Student's t-test.

In the 20-40 cm layer, the K^+ content in the initial condition (control) was 0.16 $cmol_c\ dm^{-3}$, while in the second soil sampling it was 0.59 $cmol_c\ dm^{-3}$, leading to a statistically significant difference between samplings. For the third soil sampling, a significant decrease was noticed compared to the second sampling, reaching the value of 0.17 $cmol_c\ dm^{-3}$, which is statistically similar to the K^+ content found in the control (Figure 3).

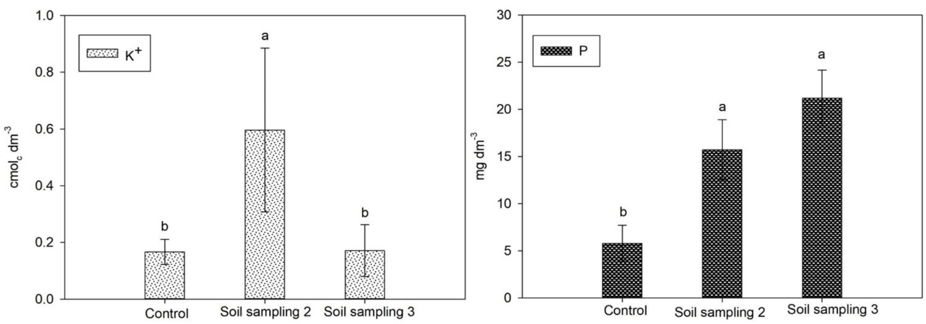

Figure 3. Means and standard deviation of K^+ and P contents in the three soil samplings of the experiment, in the 20-40 cm layer, on the north axis of the São Francisco River Integration Project. Control, initial condition (March 2016); soil sampling 2, the first generation of the cover plants (November 2016); soil sampling 3, the second generation of the cover plants (June 2017). Means followed by different letters differ statistically at the 5% probability level according to Student's t-test.

Regarding the P content in the 20-40 cm layer, the second and third soil samplings were statistically similar, with mean values of 15.46 and 21.19 mg dm^{-3}, respectively. The control was statistically inferior to the other samplings, with a mean value of 5.82 mg dm^{-3}. The other variables analyzed did not show a statistically significant difference.

Soil chemical properties

In the second soil sampling (November 2016), just after the end of the first-generation cycle of the herbaceous plants, in the 0-20 cm layer (Table 2), the soil pH means varied around neutrality, showing the basic character of the soil surrounding the transposition on the north axis of the São Francisco River Integration Project (SFIP). Soils with basic pH values are commonly found under semi-arid conditions, which can negatively affect the availability of micronutrients by making them difficult to solubilize, reducing the uptake by plants, and influencing the increase in sodium, which is very harmful to plants (Udeigwe et al., 2016). Similar results were observed in the 20-40 cm layer, in the second sampling (Table 3), and in both layers of the third sampling (Tables 4-5), in which there was no change in the soil pH values. This result shows the difficulty of reducing soil pH values.

Miranda et al. (2011) state that agronomic techniques for reducing pH values are more complex than those that refer to their increase. While liming is performed to increase the pH values, a technique commonly applied by farmers, the reduction in the pH value is usually performed using gypsum and soil washing. Sá et al. (2015), aiming to evaluate the effects of gypsum and bio fertilizer doses on the soil chemical properties in a saline-sodic soil, found a significant decrease in pH values in just over 60 days after applying the corrective. This result shows that the practice is effective, but for the purpose of recovering degraded areas, especially in the semi-arid region, one must evaluate the economic and water viability to carry out such actions.

The mean values of electrical conductivity (EC) in some treatments were higher than 4 dS m^{-1}, indicating that the soil is saline (Santos et al., 2018). High EC is a common characteristic in semi-arid soils due to irregular and scarce rainfall, poor drainage (Pedrotti et al., 2015), high temperatures, and high evapotranspiration. Additionally, there is the presence of poorly weathered soils, with a predominance of sandy texture, often shallow, or with great concentration of salts in solution or exchangeable sodium, which favor the occurrence of problems such as salinization, sodification and soil compaction (Cardoso et al., 2017).

The presence of soluble salts suggests the implementation of an external source of organic matter, such as bovine biofertilizer. Sá et al. (2015) used different doses of biofertilizer and found a decrease in the concentration of soluble salts, as the biofertilizer acted by promoting the leaching of salts, consequently, promoting the reduction of salinity. Sousa et al. (2012) also found beneficial effects of organic matter on soil salinity.

All densities of the herbaceous plants evaluated contributed to the increase in SOM; however, it was not possible to determine which plant density stood out, as no statistical difference was found between the plant density treatments. The edaphic and climatic conditions of the Brazilian semi-arid region, characterized by high temperatures, low rainfall, high evapotranspiration, presence of poorly weathered and fragile soils, and low biomass production, may favor rapid decomposition of SOM (Santos et al., 2019), which can be observed from the reduction in SOM content in the third sampling (Figure 2). In contrast, Pragana et al. (2012) state that soil organic matter is an excellent indicator of soil quality, ideal for evaluating recent management systems in which changes in organic matter are not yet in large magnitudes.

The high mean values of the percentage of sodium saturation (PSS) show that Na^+ appears in high concentration in the cation exchange capacity (CEC), reaching values around 30%. Thus, the soils surrounding the transposition on the north axis can be classified as saline-sodic according to Richards (1954a), with a basic pH, high EC (> 4 dS m^{-1}) and PSS greater than 15%. High percentages of Na^+ in the soil negatively influence the physical properties of the soil, mainly its structure and porosity due to the dispersive behavior of the colloids in the presence of Na^+, causing a migration of these particles (clay) along the soil profile, which may obstruct some macropores, increasing soil compaction (Freire & Freire, 2007). The presence of high levels Na^+ in the soil was observed during all the experimental period since there was no statistical difference in the Na^+ content and in the PSS in the soil samplings and layers evaluated (Tables 2-5).

In general, the soil under cultivation (treatments) has higher levels of macronutrients (K^+, Mg^{2+} and P) than the control, probably due to the climatic conditions of the semi-arid region, such as the low rainfall rate, which may favor smaller losses of nutrients through leaching and, consequently, their accumulation in the soil (Cardoso et al., 2017). However, in sandy textured soils, which have easily saturated adsorption sites (colloids), the increase in mobility and leaching of K^+ is favored as it is a monovalent cation (Santos et al., 2015), so its difference is more noticeable in the superficial layer, as characterized in the second sampling (Tables 2-3).

The Ca^{2+} content showed no statistical difference between the treatments in all soil samplings and layers, possibly because the Ca^{2+} content in the soil was already at levels considered good (2.41 – 4.00 cmolc dm^{-3}) and very good (> 4.00 cmolc dm^{-3}) before the experiment began, as demonstrated by the control (Tables 2-5), according to Ribeiro et al. (1999), and native herbaceous plants have low nutrient requirements (Mesquita et al., 2018). On the other hand, the Mg^{2+} content in the treatments with cover plants was statistically higher, mainly in the treatment 1.2 in the 0-20 cm layer.

For the 20-40 cm layer, the variables obtained an effect similar to that found in the first layer related to the evaluated plant densities.

Soil physical properties

The physical properties of the soil did not change significantly during the experiment in any of the soil samplings, so the cover plants do not affect soil bulk density (Bd), total porosity (TP), macroporosity (Ma) and microporosity (Mi). Studies of recovery of degraded areas using soil physical properties as soil quality indicators are usually longer, often lasting decades. A study carried out in the Midwestern United States indicated that the long-term (thirteen years) use of cover crops can raise soil water storage and improve soil physical properties (BD, Mi, Ma etc.) (Basche et al., 2016). Therefore, the short time of the experiment may not have been enough to observe physical changes in the soil. It is necessary to maintain the evaluated treatments for a longer period of time to verify statistical differences between them (Alves et al., 2011).

The Bd mean value in the SFIP areas was 1.50 g cm^{-3}, while the Ma was 14.22%. Stolf et al. (2011) state that the lower limit of soil macroporosity for adequate plant growth must be 10%. Therefore, the Ma mean value in the area surrounding the SFIP is adequate. Additionally, Stolf et al. (2011) recommend the use of limit bulk density based on the soil texture to check the soil compaction level. This index indicates which the Bd is, where Ma is 10%. In the present study, the limit BD was 1.59 g cm^{-3}, indicating that the Bd values found in the treatments are close to the limit, so this information can be used to assist in decision-making about actions to reduce soil compaction. For the third soil sampling, the mean values of the variables were very similar to those of the second sampling, as well as the critical BD, with no statistical difference between the three samplings performed.

The high concentration of sodium in the area makes it difficult to improve the soil physical conditions, as its presence influences the dispersion of clays and contributes to destroying soil structure, making it compact and with low permeability (Ruiz et al., 2004).

The stones present in the area also influence greater soil compaction (Lima et al., 2013), since at the time of sampling, in some undisturbed samples it was common to find the presence of stones and other materials from the construction of the SFIP. The number of stones found in the second layer (20 to 40 cm) was so high that it prevented sampling, indicating that this will be a limiting factor for plant growth in areas altered by the SFIP, especially for plants that have deeper roots, like shrubs and trees.

Temporal changes in soil properties after using cover plants

The highest SOM content was observed in the second soil sampling (14.7 g kg^{-1}), which was superior to the control (before the experiment), showing that the herbaceous plants promoted an increase of SOM in this period. However, the SOM content in the third soil sampling was equal (statistically) to that of the control, demonstrating that the first generation of plants, which had a good condition of initial development, showed better performance in the SOM supply, but it decreased over time (Figure 2). Therefore, it is necessary to maintain recovery techniques until reaching the ecological balance of the soil (Silva et al., 2016).

The results show a temporal evolution of SOM from the initial state to the first sampling. However, the SOM was mineralized, returning to the initial state (Martins et al., 2015). In the present study, sowing, fertilization, and irrigation clearly favored the first generation of plants, as there was an accumulation of SOM content. The second-generation plants, which appeared spontaneously (from the seed bank of the first generation) did not have the same condition; since they were grown during the rainy season, regular irrigation and fertilization were not performed, which did not favor contribution or maintenance of organic matter. Other works carried out in semi-arid regions demonstrate the rapid decomposition of SOM, mainly due to edaphic and climatic conditions (Cardoso et al., 2015; Santos et al., 2019). Santos et al. (2019), evaluating carbon stocks in fragile soils under semi-arid climate conditions, found that a long-term evaluation is necessary to understand the C balance.

The K^+ content showed the highest values in the first sampling, decreasing to the initial values in the third sampling (Figure 2). Leaching of K^+ is facilitated because it is a monovalent cation and the soil of the area is sandy (Santos et al., 2015). The changes in the K^+, P and Mg^{2+} contents are due to the initial fertilization; however for K^+, due to its high mobility, continuous fertilization is necessary to favor the remaining content in the soil solution. These results were verified in the present study, as there was a statistical difference only in the second sampling (November 2016) (Tables 2-3), while in the third sampling (June 2017) (Tables 4-5) there was no difference, due to the leaching of K^+ promoted by the rains of the region. A similar effect occurred in the 20-40 cm layer (Figure 3).

The initial fertilization promoted changes observed in the second and third samplings for the Mg^{2+} content (Figure 2). Since Mg^{2+} is divalent, its leaching is more difficult compared to monovalent cations, contributing to the maintenance of this cation in the soil (Zucareli et al., 2013). The effect of fertilization was also verified in the study carried out by Kitamura et al. (2008) in the state of Mato Grosso do Sul in an Oxisol, where the treatments with chemical fertilizers showed a faster statistical difference in the Mg^{2+} content when compared to treatments with green manure, cover plants or sewage sludge. The addition of Mg^{2+} by fertilization directly influenced SB and CEC (Figure 2), since the low potential acidity facilitates the maintenance of exchangeable bases in the soil (Ribeiro et al., 1999). CEC is influenced by the addition of fertilizers and correctives, with Ca^{2+} and Mg^{2+} being the elements that have the greatest capacity to change these variables (Dhiman et al., 2019).

The P content in the 0-20 cm and 20-40 cm layers (Figures 2-3) showed a statistical difference between the samplings compared to the control. As the mobility of P is low in the soil, its levels were maintained for longer. Additionally, with the decomposition of SOM some forms of P may have become available in the soil, promoting the maintenance of P levels (Yang et al., 2019).

CONCLUSIONS

The herbaceous plants as a technique for recovery of degraded areas increased soil organic matter (SOM) in their first generation.

The practices of recovering the degraded area of the São Francisco River Integration Project (SFIP), such as soil preparation, fertilization, and use of cover plants, improved the initial conditions mainly for SOM, K^+, Mg^{2+} and P in the first generation of plants. However, in the second generation of plants, where those practices were not performed, there was a reduction in the levels of these nutrients over time, which returned to the initial condition. Thus, it was found that the recovery of the soils of the areas altered by the SFIP should occur continuously until the stabilization of the ecological system.

Changes in soil properties due to the recovery practices were found in the topsoil layer to the detriment of the subsurface layer, where greater changes in the soil chemical properties were observed.

The short time of the experiment was not enough to verify changes in soil bulk density, total porosity, macroporosity, and microporosity. This indicates that long-term use of cover plants is needed in order to find positive effects in those soil physical properties under the experiment condition.

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