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Salinity Dynamics in Subsoiled Soils of the Northwest of the Argentine Pampean Plain

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The objective of the present work was to evaluate the annual evolution of the electrical conductivity and the reaction of the soil, in a Natraqualf of the northwest of the Argentine Pampean Plain, treated with a subsoiler and sowing of wheatgrass.

Methodology: Four treatments were established in plots of 400 m^2: natural pasture; pasture with wheatgrass (*Thynopirum ponticum*); natural pasture with subsoiling and wheatgrass pasture with subsoiling. Soil samples were extracted at depths of 0-15 cm, 15-30 cm and 30-45 cm, in January, April, July and October. The edaphic parameters analyzed were: pH, electrical conductivity and bulk density. In October, the dry matter production was determined by treatment. The monthly variation of the depth of the groundwater and its chemical characteristics was measured.

Results: The depth of the water table fluctuated between 1.30 m and 0.70 m. The implantation of wheatgrass combined with subsoiling produced a decrease in electrical conductivity from 23.7 $dS.m^{-1}$ to 3.4 $dS.m^{-1}$ at 0-15 cm, and from 18.3 $dS.m^{-1}$ to 7.9 $dS.m^{-1}$ at 15-30 cm. Soil pH decreased almost one unit in the first 30 cm of depth of the treatments that included wheatgrass. The bulk density was reduced from 1.39 to 1.03 $g.cm^{-3}$ in the treatment with subsoiling and wheatgrass, and 1.09 $g.cm^{-3}$ in the wheatgrass treatment without subsoiling. The salt concentration and reaction of the soil at more than 30 cm did not show significant changes in the course of the work.

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Conclusion: The implantation of wheatgrass, combined with the use of a “mole plow” subsoiler, in the studied soil, produces a significant decrease in the salt content and soil pH in the first 30 cm of depth. At more than 30 cm the salt concentration and reaction of the soil is determined by the groundwater

Keywords: Salinity; Thynopirum ponticum; subsoiler; electric conductivity.

1. INTRODUCTION

Although there are no precise statistics on the extent of soils affected by halomorphism, recent studies indicate that, worldwide, some 411.7 million hectares are affected by salinity, and 617.9 million by sodicity [1]. About a third of all agricultural lands are becoming saline with more than 100 countries experiencing salt-affected soil problems [2] [3]. Recent estimates indicate that, in the last 20 years, the world has lost an average of 2000 ha per day of agricultural land due to salinization [4].

Argentina is among the countries most affected by salinity and alkalinity in the world, along with Ukraine, Russia, China, United States, Canada, South Africa, and Australia [5]. The presence of saline soils in Argentina occurs in very diverse environments and its origin is both natural and induced by anthropic activities, totaling some 26 million affected hectares [6].

The problem of salinization in Argentina is of burning interest, since its potential impact on productive activities is visibly negative and there is the necessity of implement research and innovation capacity through a comprehensive approach to solve this problem [7].

In the NW of Buenos Aires, SE of Córdoba and S of Santa Fe, there is an extensive area of poor drainage, susceptible to waterlogging. When the water is eliminated and the drying of the upper layers of the soil begins, salinization and alkalinization processes take place with an intensity related to the composition and saline concentration of the phreatic [8]. The northwest of Buenos Aires, known as the sandy pampas, constitutes a region lacking a surface water network that covers about 6 million hectares. This plain is covered by longitudinal medanous cords to the north and parabolic dunes to the south, which limit surface drainage by preventing the free movement of water [9]. Thus, in humid periods, flat or slightly depressed areas keep the water on the surface behaving like temporary lagoons. This situation leads to the regional rise of the water table, which has high amounts of salts and sodium dissolved, which affect the productivity of the region's soils.

Water infiltration is very slow where the subsoils are sodic and the water does not percolate below that horizon. After the rainy season, when the water evaporates rapidly, the accumulation of salt in the layers of the sodic subsoil is exacerbated. This "transient salinity" fluctuates with depth and also changes with season and rainfall, being governed by two main factors: water and solute flow, and hydraulic conductivity of the root zone layers [10]. The hydraulic conductivity of a soil depends on both Na and total salt concentration of the filtration solution. A high hydraulic conductivity can be maintained, even with high values of percentage of exchangeable sodium (PSI), if the concentration of the solution is above a critical level [11].

The halomorphism or salinity of soils has highly variable effects on vegetation depending on the amount, persistence and type of salts [12]. The ability of plants to maintain a high cytosolic Na^+ ratio is likely one of the key determinants of salt tolerance. Maathuis et al. [13], among others, have made important advances in the identification and characterization of genes and transporters that contribute to cytosolic sodium homeostasis. Plants respond to salinity in two phases: a fast osmotic phase that inhibits the growth of young leaves and a slower ionic phase that accelerates the senescence of mature leaves. The adaptations of plants to salinity are of three different types: tolerance to osmotic stress, Na^+ exclusion, and tissue tolerance to accumulated Na^+ [14].

It is known that these soils have a limited biomass production capacity. However, productivity can be recovered and / or significantly improved with technologies designed and applied according to their structural and functional characteristics [15].

The increasing development and intensification of the problems of salinization and sodification of soils, linked to the oscillation of the depth of the water table, is associated with climatic variability (generally with rains above the historical average) and intensification in the last decades of agricultural use of the higher lands surrounding those affected. The aforementioned situation has altered the water balance and regime of depressed areas, with an increase in flooding that has caused temporary or permanent increases in the water table. This has allowed the salts and sodium accumulated in the groundwater, which did not cause problems when these were kept at greater depths, to move along with the capillary water and accumulate in the surface soil, affecting the development of the plants. The degradation of the vegetation cover due to overgrazing of non-tolerant species at the new levels of salinity and sodicity reached has contributed to the process.

These groundwater generally contain different proportions of sodium bicarbonate which, when accumulating on the surface, and partly transforming into sodium carbonate, cause the precipitation of a large part of the calcium and magnesium in the form of carbonates. With this, the proportion of sodium increases, especially in the form of sodium bicarbonate and carbonate, causing a strong alkalinization of the soils (pH above 9 -10) and the dispersion of the colloidal fraction of the soil. The consequence is the compaction of the soils, which become very hard when dry and waterproof when wet. All this frequently affects the growth and development of many plant species, by causing difficulties in the development and activity of the roots due to mechanical resistance and lack of aeration in the soil. At the same time, the infiltration and movement of the water in the soil is hindered, which favors the temporary flooding of the land in times of rain and reduces the possibilities of washing the salts accumulated in the surface soil [16].

Among the management practices of halomorphic soils, the use of different tolerant plant species, in order to increase biomass, such as wheatgrass (*Thynopirum ponticum*), creole wheatgrass (*Elymus scabrifolius*), festuca (*Festuca arundinacea*) and gramma rhodes (*Chloris gayana*), among others, has been carried out in different regions and with different results. Similarly, mechanical practices have been implemented, ranging from superficial scarifying to deep subsoiled [15]. Thus, for example, the mole plow subsoiler has been shown to improve drainage of silty loam soils located in flat areas with subnormal flat concave relief and fluctuating water table levels [17] [18].

The objective of the present work was to evaluate the annual evolution of the electrical conductivity and the reaction of the soil, in a Natraqualf of the northwest of the Plain Pampeana Argentina, province of Buenos Aires, treated with a mole plow subsoiler and wheatgrass sowing, in relation to the soil with natural pasture.

2. MATERIALS AND METHODS

The experiment was carried out at the Miraflores Establishment, located 7 kilometers south of the town of Pasteur, Carlos Tejedor, Province of Buenos Aires, Argentina.

The test soil is classified as Natraqualf and has been developed from recent sandy materials of variable thickness that have been retransported by wind processes. They are settled on sandy silts of the Pampeano, being these also of eolic origin, of medium fine texture and little permeability. The contact between both materials conditions the distribution of water on the surface as it constitutes the first obstacle that retains the subsurface waters as a phreatic. The depth of this water table depends on the thickness of the sandy mantle. The water is kept far from the surface in deep soils, where the relief is undulating but it emerges where the coverage is scarcer, in coincidence with the lines and depressed areas.

At the time of the beginning of the test, the soil was covered by natural species, with a strong predominance of *Distichlis spicata*. In order to favor the sowing and implantation of the forage species tested for recovery, the natural pasture was dried using a graminicide at a rate of 2 liters per hectare.

The effects of a biological treatment, sowing of wheatgrass; one mechanical, use of a “mole plow” subsoiler; and the combination of them were evaluated and compared with a witness treatment. Therefore, four plots of 50 x 8 m were established with four treatments: T1- natural pasture; T2- pasture with wheatgrass; T3- mole plow on natural pasture; T4- mole plow with wheatgrass sowing.

The “mole plow” subsoiler is made up of a rudder or subsoiler blade, a 6-centimeter diameter grating or beveled foot, and a 10-cm diameter metal sphere attached to the foot with a chain, whose function is to shape the cylindrical gallery drain, open in the subsoil. The application of this tool was carried out in order to improve water infiltration, increase the leaching of salts in depth and improve soil aeration. The cylindrical gallery that said implement builds in depth, can contribute to the better drainage of these soils and thus to moderate the rise of the water table, within reasonable limits.

The mechanical work of the subsoiling was carried out at a depth of 0.45 meters, with a spacing of one meter between passes. All the work was carried out in the direction of the slope, ending in the lowest area of the lot.

The wheatgrass (*Thynopirum ponticum*) was sown in March with a direct seeder and a density of 30 kg. ha^{-1}. The wheatgrass is a species of easy implantation in these soils, presenting a slow initial development, but which comes to completely cover the soil.

In the month of October, forage production was evaluated in each plot taking 12 samples of $1m^2$ for each treatment, separating the weed from the pasture. Then the green matter production was determined and the dry matter content with an aliquot by drying in an oven to constant weight.

Soil sampling was carried out at 6 points of each treatment, 10 meters apart, taking a sample composed of five subsamples at each point. The sampling depths were as follows: 0 - 15 cm, 15 - 30 cm and 30 - 45 cm. In the months of January, April, July and October, the electrical conductivity of the saturation extract was evaluated, while the pH was evaluated in the months of January and October. The bulk density was determined by the cylinder method at the beginning of the test in January, and at the end, in October, taking 6 samples in each treatment.

The underground water from the water meter installed in the test was analyzed. Electrical conductivity, pH and solid residue were evaluated. The concentrations of the following ions were determined: Ca^{+2} and Mg^{+2} (atomic absorption method); Na^+ and K^+ (flame photometry method); $(CO_3H)^-$ (titration method); Cl^- (argentometric titration method) and $(SO_4)^{-2}$ (turbidimetry method). The obtained results were evaluated using descriptive statistics techniques. One-way analysis of variance (ANOVA) and Fisher's Least Significant Difference (LSD) test were used.

3. RESULTS AND DISCUSSION

The textural characteristics and some chemical properties of the soil in the test, prior to it, are listed in Table 1. In this table, the halomorphic character of the soil is clearly exposed.

The groundwater of the northwest of Buenos Aires is generally constituted by sodium and bicarbonate. During the months of April and May, due to the occurrence of intense and frequent rains, together with less evapotranspiration, a critical period occurs in which the water table rises, with a very high concentration of salts (Tables 2 and 3).

The fluctuations of the water table in underground flow discharge areas and their influence on the concentration of salts in the soil has been studied by various authors [19] [20]. These fluctuations, together with the use and management of the soil, impact on the saline content of the same at different depths as shown in Fig. 1.

Fig. 1 presents the monthly evolution of the EC, at different depths, compared to the treatments carried out. The precipitations of April and May produce an increase in the water table (Table 2). As the rains decrease, the soils dry out due to infiltration and evapotranspiration, starting to generate the salinization process [21]. This process can be clearly observed in the control treatment with natural pasture (T1) in which three phases are recognized. The first one is related to the rise of the saline solution by capillarity. Evapotranspiration increases with increasing temperatures and spring winds, acting as a force that sucks up the saline solution through the pore space in the soil. The second phase consists of the saline concentration in the surface horizon as a function of the factors mentioned above. The third phase of the salinization process is the formation of the saline crust on the surface, which is particularly visible in the hot, windy and dry season of spring. These efflorescences and saline crusts express the most intense degree of salinization and in these soils, they exceed 20 $ds.m^{-1}$ of electrical conductivity. Indeed, in this treatment a similar conductivity to the initial one is observed in the three depths studied until the sampling in July. In the month of October, as a result of the three-phase cycle mentioned, a significant increase in conductivity is observed due to capillary rise and saline concentration on the surface, as a result of the increase in evapotranspiration due to higher temperatures and winds. Thus, the conductivity reaches 23.7 $ds.m^{-1}$ (±1.5) from 0 to 0.15 m, and 18.3 $ds.m^{-1}$ (±1.7) from 0.15 to 0.30 m. The electrical conductivity from 0.30 to 0.45 m remains unchanged, since it is governed by the conductivity of the water table.

Table 1. Soil characteristics

Horizon	Ap	BA	Btn	Bt2	BC	C
Depth (cm)	0-24	24-39	39-53	53-70	70-105	105-120+
Texture						
Clay %)	9.8	14.9	28.8	32.1	19.0	14.7
Silt (%)	50.6	47.1	41.3	40.8	41.6	41.1
Sand (%)	39.6	38.0	29.9	27.1	39.4	44.2
Textural class	Silt loam	Loam	Clay loam	Clay loam	Loam	Loam
EC ($dS.m^{-1}$)	14.9	13.0	12.5	13.7	12.8	12.0
pH (1:2,5)	9.0	8.6	8.5	8.3	8.2	8.2
SAR	36.22	33.01	32.37	31.82	31.71	30.66

EC: electrical conductivity; SAR: sodium adsorption ratio

During the months of January and April, the treatments did not produce statistically significant differences in the values of electrical conductivity at different depths; however, from 0 to 15 cm and from 15 to 30 cm reduced the EC values. On the contrary, in July and October, significant variations were registered in the saline contents of the surface samples, 0 to 15 cm and subsurface, 15 to 30 cm, as a result of the different treatments. Between 30 to 45 cm, as happened with the soil of the natural pasture (T1), the EC remained at similar values throughout the trial period, confirming that in the deep samples the treatments have not had a response in the months evaluated.

Table 2. Monthly depth of the water table

Month	Depth (m)
January	1.10
February	1.15
March	1.30
April	0.70
May	0.70
June	0.75
July	0.75
August	0.80
September	1.00
October	1.10
November	1.10
December	1.20

The treatments T2, T3 and T4 produced statistically significant decreases in the EC of 0-15 cm and 15-30 cm of depth in the months of July and October, with respect to the control soil T1. In this last month, the highest surface saline contents were determined in the soil with natural pasture (T1), where an average EC of 23.7 $dS.m^{-1}$ was recorded, while in the soil with wheatgrass and use of a mole plow (T4) a mean EC of 3.08 $dS.m^{-1}$ (±0.7) was determined, resulting in the lowest of the entire test. On the same date, the subsurface samples, from 15 to 30 cm, decreased from 18.3 $dS.m^{-1}$ in T1, to 7.9 $dS.m^{-1}$ (±1.5) in T4. During the month of July, the same effect of the treatments on the EC is observed.

Fig. 1 allows us to affirm that both the use of the mole plow (T3, T4) and the sowing of wheatgrass (T2) produced a decrease in the saline content of the soil from the surface to 30 cm deep.

Disaggregating the effects of the treatments, the following was observed:

- The evolution of electrical conductivity in the different treatments throughout the quarterly samplings carried out showed the effectiveness of the treatment with wheatgrass (T2) implantation to achieve a marked decrease in salinity [22]. This decrease was manifested more intensely in the superficial portion of the soil (0 to 15 cm), where the mean conductivity was 3.4 $dS.m^{-1}$ in the month of October. At the depth of 15 to 30 cm, a noticeable decrease in conductivity was also recorded. The vegetation cover and surface residues of the wheatgrass pasture reduced the direct evaporation of water at the soil surface and thus decreased the capillary rise of the groundwater in the soil profile. In this sense, Degioanni et al. [15] point out as an exclusive principle for the recovery of soil productivity like the one analyzed, the need to cut the upward flow of salts from the water table to the soil surface. Additionally, the implanted pasture, through its root system, was able to improve the permeability of the superficial soil and thus facilitate the infiltration of rainwater for the displacement of salts and sodium towards the groundwater maintained at an adequate depth. This depth would be the one that Cisneros et al. [19], Degioanni et al. [15] and others call it "critical depth"; defining it as one in which the salts dissolved in the layer are capable of reaching the soil surface by capillarity and producing an accumulation of salts to inhibit the germination and development of plants. However, the effectiveness of this system can always be affected by climatic factors, especially by excesses in rainwater that can cause new uncontrollable rises in the water table.

Table 3. Composition and average saline content of groundwater

Parameter (unit)	Valor
EC (dS.m^{-1})	12.0
pH	8.2
SAR	63.5
Dry residue (g.l-^{1})	8.1
Cations	
Ca^{+2} (mg. l-^{1})	40.3
Mg^{+2} (mg. l-^{1})	45.0
Na^{+} (mg. l-^{1})	2500.0
K^{+} (mg. l-^{1})	50.4
Anions	
$(CO_3H)^{-}$ (mg. l-^{1})	990.0
Cl^{-} (mg. l-^{1})	2600.0
$(SO_4)^{-2}$ (mg. l-^{1})	1400.0

EC: electrical conductivity; SAR: sodium adsorption ratio

- The application of the mole plow on the natural pasture (T3) caused a slight decrease in surface salinity from the autumn rains. This decrease with respect to the January sampling is observable in the April and July samplings in which the conductivity decreased slightly more than 3 ds.m^{-1} at depths of 0 to 30 cm. However, this treatment did not achieve a sustained decrease in salinity in the October sampling. This is attributable to the low ground cover provided by the natural pasture and the partial sealing of the cracks opened by the rudder and the gallery in depth, due to the unstable subsoil materials.

- The mole plow treatment with wheatgrass implantation (T4) produced a decrease in salinity (not statistically significant) in the April sampling, in a similar way to that produced in the mole plow treatment on natural pasture (T3) by improving the drainage conditions of the profile from the soil which facilitates the leaching of salts [23] [24]. In the July and October samplings, T2 and T4, without significant differences between them, produced the greatest decrease in electrical conductivity with respect to T1, for which this decrease is mainly attributable to the effects of the wheatgrass.

Regarding the soil reaction, the pH measurements carried out in the month of October show a decrease close to one unit in the depths of 0-15 and 15-30 cm, in the two treatments that include wheatgrass, T2 and T4 (Fig. 2), [25], while no significant changes in pH were recorded in the treatment with subsoiling (T3), with respect to the natural pasture (T1). The possible causes of the decrease in pH were already commented on when talking about the effect of the activity of the radical system on the decrease in salinity and sodium. Despite the decrease in pH mentioned in the treatments with wheatgrass, the soil continues within the alkaline range, taking into account the strong sodium character of the environment. In the deepest samples, 30 to 45 cm, the treatments had no effect on pH, confirming the maintenance of saline conditions exerted by the water table in this area of the soil.

The variations in initial and final bulk densities determined in the different treatments (Table 4) show significant improvements in the physical condition of the soils treated with wheatgrass, in relation to the natural pasture.

Table 5 shows the dry matter production of the natural pasture and the wheatgrass implanted in the two treatments. The subsoiling with a mole plow managed to increase the production of dry matter in relation to the natural pasture, although it remained within a low range of productivity. The treatment with wheatgrass and mole plow achieved maximum productivity, due to the improvement of the aeration conditions and salt and sodium leaching achieved in the profile.

In regions such as the one studied, where the water table is shallow, it is essential to carry out an integrated analysis of landscape elements that include, define and characterize groundwater flows. Fagundo-Castillo et al. [26] point out that the selection of management practices is feasible from the definition of the type of flow and its joint analysis with the geomorphology, soils and vegetation. It should be considered that the management of the depressed sectors in which the salinization processes are intensified, should be complemented with a good management of the higher areas. In these there are runoffs from the hills and mid-hills that increase the temporary flooding and waterlogging of the shallows. Bio-drainage techniques for local recharge and flow transit areas can constitute a management alternative with positive effects [27]. Likewise, it is important to use good practices that tend to retain rainwater in the place where it falls, avoiding or delaying the runoff towards the shallows and lagoons.

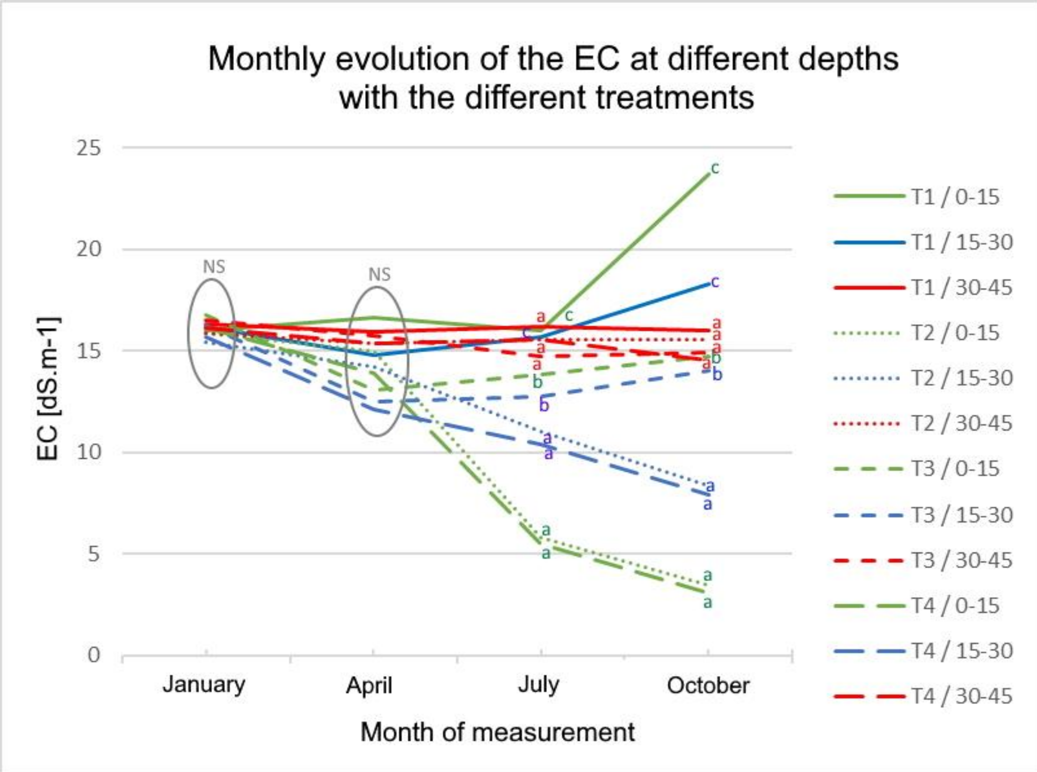

Fig. 1. Monthly evolution of the EC at different depths with the different treatments
Lines of the same color correspond to the same depth of samples; Different letters for the same depth indicate significant differences between treatments (p = .05); Different styles of lines correspond to different treatments; NS: indicates general absence of statistical significance between treatments, for a given date of

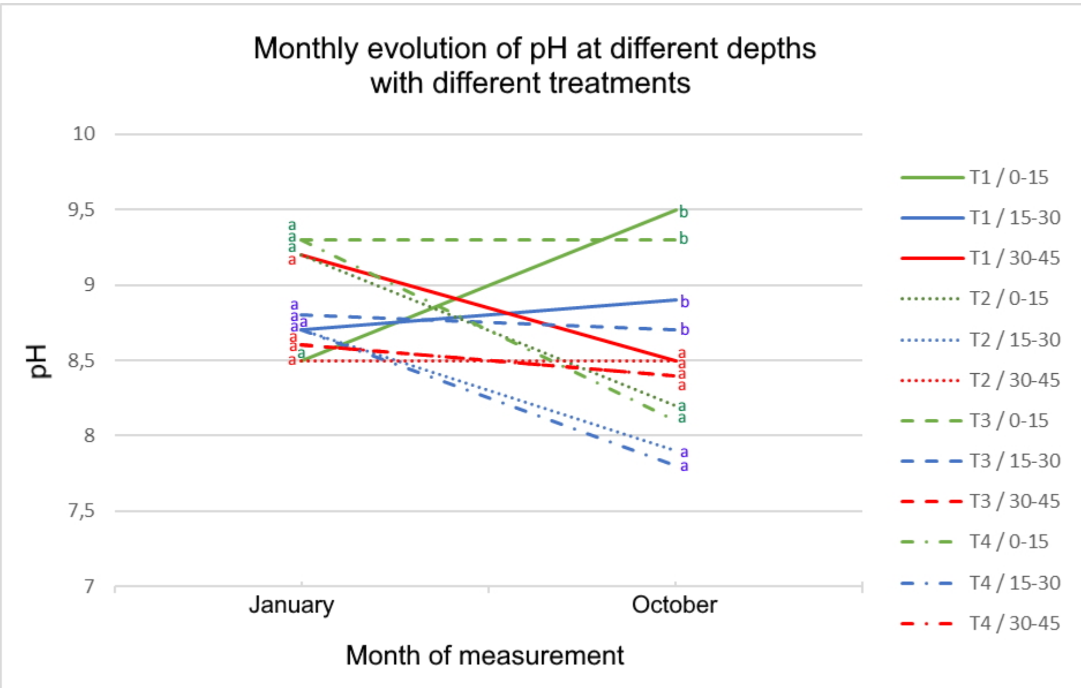

Fig. 2. Monthly evolution of pH at different depths with different treatments
Lines of the same color correspond to the same depth of samples; Different letters for the same depth indicate significant differences between treatments (p≤ 0.05); Different styles of lines correspond to different treatment

Table 4. Mean bulk density of treatments

Treatment	Bulk density ($Mg . m^{-3}$)	
	Initial	Last
Natural pasture	1.39 (±0.12) a	1.42 (±0.10) a
Subsoiled natural pasture	1.42 (±0.11) a	1.38 (±0.13) a
Subsoiled wheatgrass pasture	1.38 (±0.10) a	1.03 (±0.11) b
Wheatgrass pasture	1.36 (±0.14) a	1.09 (±0.09) b

Different letters show significant differences between treatments (p= .05)

Table 5. Production of dry matter in the different treatments

Treatment	Dry matter ($Kg. ha^{-1}$)
Natural pasture	410 (±32) a
Subsoiled natural pasture	640 (±53) a
Subsoiled wheatgrass pasture	3550 (±176) c
Wheatgrass pasture	2730 (±188) b

Different letters show significant differences between treatments (p= .05)

4. CONCLUSION

The implantation of wheatgrass, combined with the use of a "mole plow" subsoiler, in the studied soil, produced a significant decrease in the salt content and soil pH in the first 30 cm of depth. This treatment also improved physical conditions through the contribution of biomass and root activity. The salt concentration and reaction of the soil at more than 30 cm were determined by the groundwater and weren't affected by the treatments tested.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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