CHANGES IN A SODIC SOIL AFTER GYPSUM APPLICATION UNDER DRYLAND CONDITIONS

Elena Bonadeo, MSc
Ines Moreno, MSc
Andres Baranda, Agronomist
Cecilia Milan, MSc Candidate
National University of Río Cuarto and
National University of Villa Maria, Córdoba, Argentina

Abstract

In the Province of Cordoba Argentina there are 2.803.000 ha of soils that are sodic from a depth of around 20 cm, 93.000 of which are in San Martin department where the study area is situated. These soils, generally loam - textured soils, occur in mildly depressed areas. Paddocks frequently show uneven crop growth, named “patchy growth”, where sectors of lower plants alternate with sectors of higher plants that look normal (N). The main objective of this study is, then, to evaluate the effect of gypsum on soil properties. The treatments were **MD (**maximum dose) at a rate of 3350 kg ha^{-1}, **AD (**agronomic dose) at a rate of 1340 kg ha^{-1} of gypsum and **C** without gypsum. Gypsum was spread manually over the soil. Three years later, more gypsum was applied to **AD** (1340 kg ha^{-1})**.** Five years after the first application of gypsum, in the second horizon, the higher dose of gypsum **(MD)** lowered soil pH (H_2O), soil strength and water content held at all matric potentials, and also increased soil permeability increased. The lower and partitioned dose **(AD)** had a detrimental or no effect on the properties evaluated. Probably the lower dose was insufficient to modify the subsuperficial permeability and leaching was decreased.

Keywords: Saturated hydraulic conductivity, soil pH, soil strength, soil-water characteristic curves

Introduction

In the Province of Cordoba Argentina, there are 2.803.000 ha of sodic soils and 93.000 ha in the department of San Martin (INTA, 1993a) where the study area is situated. These soils belong to the geomorphologic region called Pampa Loessica Plana (INTA, 1993b) and generally occur in mildly depressed areas, where water horizontal movement is very slow. Paddocks, in this region, frequently show uneven crop growth, named "patchy growth", where areas of lower plants alternate with areas of higher plants that look like normal. This symptoms are similar to the symptoms mentioned by Rengasamy (1997) for sodic soils of Australia and and are attributed to the heterogeneity in the accumulation of sodium.

These soils, generally loam - textured soils, are sodic from a depth of around 20 cm, exhibit very high exchangeable sodium percent (ESP) increasingly in profundity (INTA, 1993a). Manifest inadequate soil physical behaviour as poor soil-water and soil-air relations that negatively affect the growth of most crops, as mentioned by So and Aylmore (1993) for sodic soils. Reclamation of sodic soils is needed in this extensive area.

Abundant literature on the effect of gypsum on sodic and saline-sodic soils is available (Qadir et al., 1996; Ilyas et al., 1997; Sharma, 1986; Costa and Godz, 1999; Makoi and Ndakidemi, 2007). Due to the lower permeability of these soils, the Na that has been replaced by Ca supplied by gypsum or any other calcium amendment, instead of being leached stays suspended or moves very little to the lower depths (Ilyas, 1997; Bonadeo et al., 2009). However, it is known that salts diminish noticeably effects of exchangeable sodium on decreasing permeability (Rengasamy, 1997).

Although considerable research has been done on the effects of gypsum on soil properties in many regions, but this is not the case in the region situated in the center-east of the province of Cordoba, where research on the subject is still needed. It is important to study the correct dose, the time required for improving soils, the effect on soil properties and crops, among other things.

The main objective of this research is, therefore, to evaluate the effect of gypsum on soil properties of a sodic soil of Cordoba, Argentina.

Materials and Methods

Location

The study area was located near Villa Maria (32º 29' LS y 63º 17' LO, 190 m height) in the center of the Province of Cordoba, Argentina. According to climatic data for the last 20 years, this area received about 800 mm of annual rainfall. More than 80 % of the rainfall fell from October to March (INTA, 1987). The area has a mean annual temperature of 16.5 °C. In the selected paddock, crops showed areas of little or null growth (called patch) and areas of higher growth (called normal) (Figure 1). Some soil properties for both areas (Tables 1 and 2) are shown in Bonadeo et al. (2006). The soil is a loamy typical Haplustol (INTA, 1987) with alcalinity fase.

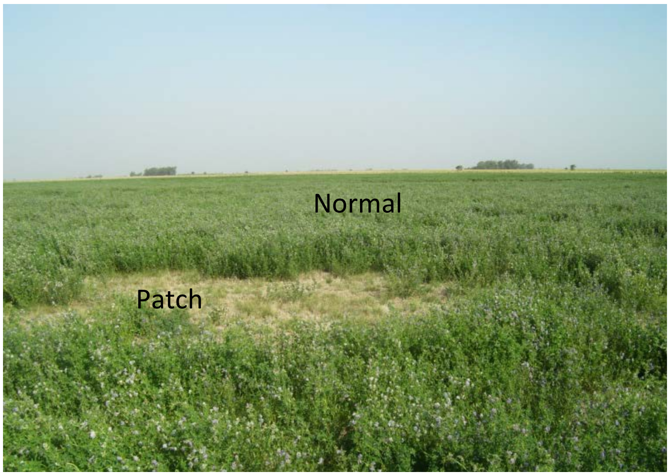

Figure 1. "Patch" and "normal" areas in the alfalfa crop.

Table 1. Morphological properties of soil in "Normal" areas and "Patch" areas

"Normal"				"Patch"			
Horiz.	**Depth** (cm)	**Texture**	**Structure**	**Horiz.**	**Depth** (cm)	**Texture**	**Structure**
A	0 - 26	Silty loam. Lim	blocky.	A	0 - 24	Silty loam Lim	blocky
Bw	26 - 37	Silty loam.	blocky	Bw_1	24 - 43	Silty loam	blocky
Bwk	37 - 55	Silty loam Lim	blocky . sa.me.	Bw_2k	43 - 66	Silty loam Lim	blocky
BCk	55 - 90	Silty loam. Lim	blocky. sa.deb.	Ck1	66 - 96	Silty loam	massive
Ck	> 90	Silty loam. Lim	Massive	Ck2	> 96	Silty loam mloamran.	massive

Table 2. Physico-chemical properties of soil in "Normal" areas and "Patch" areas

"Normal"				"Patch"			
Depth (cm)	**pH**	**CEC**[(1)] ($cmol_c\ kg^{-1}$)	**ESP**[(2)] (%)	**Depth** (cm)	**pH**	**CEC**[(1)] ($cmol_c\ kg^{-1}$)	**ESP**[(2)] (%)
0-26	6.88	12.6	2.4	0-24	7.26	11.70	12.4
26-37	7.80	14.3	12.4	24-43	9.14	13.36	33.0
37-55	8.62	14.3	14.2	43-66	9.83	12.60	42.0
55-90	9.33	13.0	23.4	66-96	9.85	13.00	43.9
> 90	9.56	10.9	39.7	> 96	9.90	10.20	45.1

[(1)] Cation exchange capacity; ([2)] Exchangable sodium percentage.

Experimental layout

In January of 2005 three blocks were laid in a "patch" area, in a randomized complete block design. In each block the treatments were, **MD (**maximum dose) at a rate of 3350 kg ha $^{-1}$ of $CaSO_4.2H_2O$ (5000 kg ha^{-1} of commercial gypsum), **AD (**agronomic dose) at a rate of 1340 kg ha^{-1} (2000 kg ha $^{-1}$ of commercial gypsum), **C** without gypsum and **N "**normal" area also without gypsum. The plot sizes were 3.50 x 3.50 m. In MD and AD gypsum (67 % pure, powder) was spread manually over the soil. In April 2008, 1340 kg ha^{-1} more were applied to **AD. DM** dose correspond to the gypsum quantity needed to change the ESP of 33 to 15 % for the layer between 24 and 43 cm and **DA** correspond to the rate usually applied by farmers.

Sampling

Five years after the beginning of the study (April 2010) five soil samples were collected from each plot, at 0–24 and 24–43cm, to make a composite soil sample to be analyzed.

Field measurements

Saturated hydraulic conductivity (Ksat) was measured with a stress disc infiltrometer (Gil, 2002). The device has a 120 mm disc and was placed over the second horizon (24 cm). Readings were recorded until stabilized (approximately 2 h).

Soil strength -up to 50 cm- was measured using a hit penetrometer Villegas® with a cone angle of 30° and a base diameter of 12 mm. Means of three measurements per plot were taken for calculation.

Bulk density: two cores per plot were collected with a gentle hand-hammering stainless steel cylinders (Inside diameter: 7.8 cm; height: 5 cm) according to the method proposed by Klute (1986).

Laboratory methods

Soil pH was measured in a 1:2.5 soil: water ratio (Page et al., 1986).

Exchangeable Na was extracted with a buffered neutral 1 mol L^{-1} NH_4OAc solution (Rhoades, 1986) and measured by flame emission spectrophotometry.

Exchangeable Na percentage was calculated as in Richards (1954) as follows:

$ESP = (Na\ exch/\ CEC) \times 100$

Where ESP = Exchangeable sodium percentage.

Soil Organic Matter was determined as in Page et al. (1986).

Soil-water characteristic curves (relationship between water content and suction) were done passing soil through a 2 mm sieve, then saturated for 24 h, after which soil was equilibrated on a pressure-plate apparatus at 30, 100, 200, 500, 1000 and 1500 kPa for 72 to 96 h (Klute, 1986).

Statistical Analysis

Analysis of variance was computed using Infostat (2010) and When ANOVA generated a significant F-value ($P \leq 0.05$) for treatments; treatment means were compared by the Least Significant Different (LSD).

Results and Discussion

Soil pH

In the first depth there are not significative differences of pH among treatments (Table 3). In the second depth AD is significantly different from MD. The lower pH value of MD could be attributed to the higher content of Ca -and its corresponding salts- from the amendment. Furthermore, it is widely accepted that soil pH decreases because of gypsum application (Costa & Godz, 1999; Sharma, 1986; Bonadeo et al., 2009) due to the higher content of sulfate ion (Quintero et al., 2004). Also, Ilyas et al. (1997) studied the influence of gypsum applications combined with crops and did not find individual or combined effects at the end of six months. They found, however, that gypsum applications decreased pH in the top 20 cm soil after one year.

Table 3. Soil pH after five years of gypsum application.

Depth	**pH**			
	C	**AD**	**MD**	**N**
cm				
0-24	6.63 a	6.90 a	6.69 a	6.82 a
24-43	8.21 a	8.94 b	7.38 a	8.39 a

Different letters in the same row indicate statistically significant differences (p<0.05).

The higher pH of AD in the second depth (Table 3) could be attributed to the higher content of soluble sodium, due to leached sodium of the first depth and to the exchangable sodium replaced with calcium from the amendments that caused CO_3Na_2 or CO_3HNa. These salts are the reason of the high pH (Darab, 1981) in sodic soils. These salts were not leached, probably due, to the low permeability and smaller quantity of macropores at a depth between 43 and 66 cm caused by the high ESP. Also dispersed particles, especially clay particles and silt particles to a lesser degree, could cause plugging of soil pores that impedes water flow. Warrence et al. (2002) mentioned this effect. In MD this effect was avoided due to the higher quantity of calcium from the amendments.

Soil strength

Possibly, the high soil strength of AD between 24-43 cm, 1.81 MPa, could be due to the fact that original sodium content was increased with sodium leached from 0-24 cm, explained by the high pH found, as showed in Table 3. The Ca supplied by the amendment was not sufficient to prevent a deleterious effect on the structure and hence caused high soil strength. Lebron et al. (2002) concluded that the more the gypsum in sodic soils the less breakdown of aggregates. This effect would be responsible for high soil strength (1.81 MPa) while in MD, leaching of sodium from the first horizon also occurrs, but the higher content of calcium from the amendment prevents dispersion from occurring. Rengasamy & Olsson (1991) mentioned that if clay particles –at the same humidity content- are calcium saturated the interparticle distance is lower than when clay particles are sodium saturated, therefore soil strength is higher in the latter.

Table 4. Soil strength after five years of gypsum application.

Depth	**pH**			
	C	**AD**	**MD**	**N**
cm				
0-24	6.63 a	6.90 a	6.69 a	6.82 a
24-43	8.21 a	8.94 b	7.38 a	8.39 a

Different letters in the same row indicate statistically significant differences ($p<0.05$).

Studies conducted by Radcliffe et al. (1986) concluded that Ca content and ionic strength increase clay flocculation, causing a change in shear modulus, which could influence penetrometer resistance. Rengasamy et al. (1984) said that in the soil there are repulsive and attractive interparticle forces being the latter the one responsible for higher soil strength and that they occur when the distance between particles is small. In the depth between 0-25 cm the differences between treatments could be attribuited mainly to external forces like animal tramping or machine traffic.

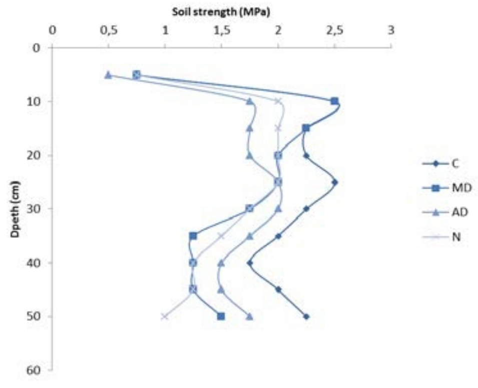

Figure 2. Soil strength curves according to treatments between surface and 50 cm.

Changes of soil strength after gypsum application in the soil profile indicated higher sodicity of deeper layers in treatment C (Figure 2). Higher sodicity of deeper layers in "patch" limits alfalfa roots growth (Bonadeo et al., 2006). Some experiences show that in gypsum-amended plots, leaching of soluble salts and exchangable Na, after one year, was enhanced by alfalfa roots that increased macroporosity, these higher macroporosity contributed to the flow in the macropore system permeability (Frenkel et al., 1989).

Bulk density

About bulk density, the results showed a significant difference, in the second depth, between AD and C (Table 5). The decrease of AD of about 5 % could be attributed to the high humidity content at sampling. The higher content of sodium caused colloid expansion and less solid was extracted by the cilinder. This effect is mentioned by Varallyay (1981). In MD, the soil bulk density was not affected. However, some authors mentioned decrease of bulk density when gypsum is applied to sodic soils, but the moisture content at the moment of determination was not mentioned. The application of gypsum increases soil macroporosity (Chartres et al., 1985; Greene et al., 1988). However, most of these effects are limited to shallow depths

Table 5. Bulk density after five years of gypsum application

Depth	pH			
	C	**AD**	**MD**	**N**
cm				
0-24	6.63 a	6.90 a	6.69 a	6.82 a
24-43	8.21 a	8.94 b	7.38 a	8.39 a

Different letters in the same row indicate statistically significant differences ($p<0.05$)

Hydraulic conductivity

Five years after applying gypsum, the hydraulic conductivity of AD at 24-43 cm depth was significantly lower than the hydraulic conductivity of MD (Table 6). This low hydraulic conductivity is attributed to obstruction of macropores by dispersed particles of clay and silt which was promoted by higher sodium content and lower electrolyte concentration. Rengasamy and Olsson (1991) reports that on the drying of the soil aggregates in dispersed material the clay particles settle in the pores, with clay particles on top of the others. Thus, they may seal the pathways for air and water. The resulting product is dense, slow permeable clods. On the other hand the highest value of DM could be attributed to the high content of calcium from the amendment that prevented dispersion and maintained macroporosity. The electrolytic effect of DM on permeability must also be considered. Ilyas et al (1997) observed that gypsum application increased the soluble Na^+ in the top 20 cm of a typic Natrustalf. Micromorphological observations carried out by Greene et al. (1988) suggest that the increase in hydraulic conductivity following gypsum treatment is associated with an increase in visible macropores and reduced clay dispersion.

Table 6. Soil hydraulic conductivity between 24-43 cm after five years of applying gypsum.

Depth	pH			
	C	AD	MD	N
cm				
0-24	6.63 a	6.90 a	6.69 a	6.82 a
24-43	8.21 a	8.94 b	7.38 a	8.39 a

Different letters indicate statistically significant differences ($p<0.05$).

Relationship between soil water content and soil water potential

For the first depth (between 0-24 cm) no significant differences among C, AD and MD were found in the relationship between soil moisture content and matric suction (Figure 3), only N showed significant higher water content with respect to each matric potential. The low sodium content of this depth may have determined the lack of response to the amendment.

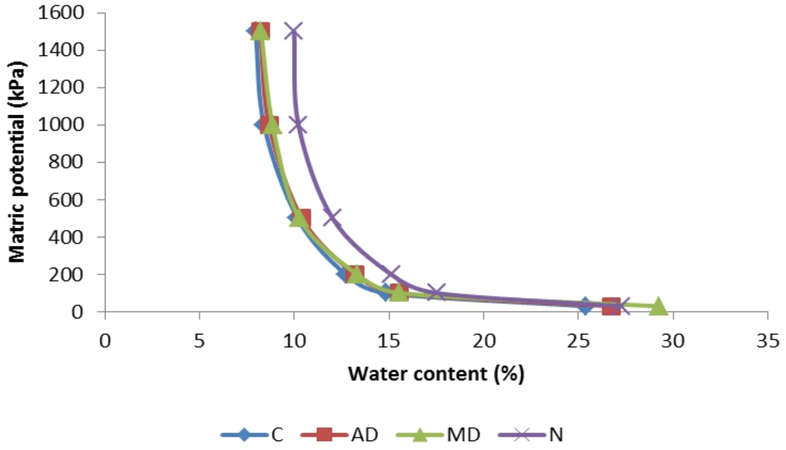

Figure 3. Relationship between matric potential and water content between 0-24 cm depth.

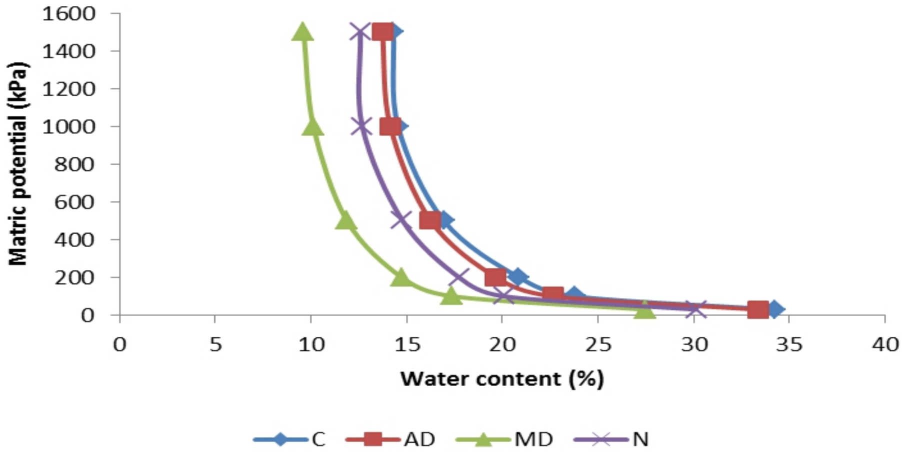

Figure 4. Relationship between matric potential and water content between 24-43 cm depth.

The MD treatment, at a depth between 24-43 cm, shows lesser water content with significant differences ($p>0.05$) at all suctions, but the differences were higher especially at high matric potentials (Figure 4). It is likely that the higher quantity of calcium of MD -between 24-43 cm- deep may have prevented micropore generation and therefore a minor quantity of water was held between 20 and 1,500 kPa. This effect was mentioned by Varallyay (1981). Dane & Hopmans (2002) also mentioned that water content is very dependent upon the arrangement of the solid particles. Lower water content at high matric suctions is an important aspect related to plant water availability.

The amount of gypsum in the case of AD, did not cause changes compared to the control (C) (Figure 4). This may be due to leaching of accumulated sodium from the first depth that caused Na_2CO_3 and to the lower calcium content of the amendment that did not prevent micropores generation. Sodium salts capable of alkaline hydrolysis (Na_2CO_3) increased water retention within the whole suction range, resulting in higher total porosity (0 kPa), field capacity (30 kPa) and “wilting percentage” (1,500 kPa) (Varallyay, 1981).

Conclusion

The higher dose of gypsum, decreases soil pH, soil strength and water content held at all matric potentials, and increases soil permeability in the second horizon and the lower and partitioned dose had detrimental or no effect on the properties evaluated probably because was insufficient to modify subsuperficial permeability and leaching was decreased. It is probable that these effects may vary with time.

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