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# Quality assessment of irrigation water under a combination of rain and irrigation

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ABSTRACT

Supplementary irrigation is one of the proposed management practices to increase the area under grain production mainly in the Humid Pampas (HP). The most common source of irrigation water in the HP comes from groundwater and is characterized by its high sodium bicarbonate content. However, the effect of the combination of irrigation and rain water on the chemical and physical properties of soils, especially when irrigation water comprises water with sodium bicarbonate, is still not well documented. The objective of the present study is to establish irrigation water suitability criteria under conditions of combined rain and irrigation. The trials were carried out on six irrigated plots and another five plots were chosen for validation purposes. Hydraulic conductivity and bulk density were measured in the field. Soil chemical analysis was performed on undisturbed soil samples. Supplementary irrigation using sodium bicarbonated water raises the soil electrical conductivity (ECe), the pH, exchangeable sodium percentage (ESP), soil sodium adsorption ratio (SARe) and cation exchange capacity (CEC) which produces an increase in bulk density ($\delta_b$), reducing the overall porosity of the soil. The effect of the soil SAR on the soil hydraulic conductivity ($K$) was evident when the soil SAR levels were greater than 3.5. The dilution factor proposed in this study allows the classification of water for supplementary irrigation linked to the management of irrigation.

## 1. Introduction

The Argentine Pampas, an area that extends over 30 Mha, is an important region for crops and animal production. During the 20th century, the Pampas was transformed into a mosaic of agricultural land divided up by grazing and farming activities. Today, the agricultural land in the Argentine Pampas is used for growing soybeans (19.7 Mha), wheat (3.7 Mha) and maize (5.7 Mha) (Hall et al., 1992 and Ghersa et al., 2002). The agri-food strategic plan aims to increase the area under grain production in Argentina by 14% (PEA, 2010). Supplementary irrigation is one of the proposed management practices to increase the area under grain production mainly in the Humid Pampas (HP).

The most common source of irrigation water in the HP comes from groundwater and is characterized by its high sodium bicarbonate content (Galindo et al., 2007). This type of water tends to precipitate to CO$^{3=}$ and HCO$^{3-}$ and, therefore, increases the soil's sodium adsorption ratio (SARe) (Rhoades, 1982). In the humid and sub-humid regions like the HP where the mean annual rainwater is 950 and 760 mm, respectively, rain water is the main water supply, supplemented by irrigation water (Costa 1999). Some authors suggest that in coarse soils, when illite dominates the clay section, supplementary irrigation with sodium bicarbonated water would not be sustainable (Vázquez et al., 2006). However, the effect of the combination of irrigation and rain water on the chemical and physical properties of soils, especially when irrigation water comprises sodium bicarbonated water, is still not well documented.

Hapludoll and argiudoll soils of the Argentine HP, using supplementary irrigation with sodium bicarbonated water with levels of sodium adsorption ratio SARw > 3, increased the exchangeable sodium percentage (ESP) to a range of 3–8 without producing an increase in soil electrical conductivity (ECe) ECe < 1.0 dS m$^{-1}$ (Irurtia and Mon, 1998; Peinemann et al., 1998; Andriulo et al., 1998; Pilatti et al., 2004). Although those ESP levels are relatively low, the farmers noticed waterlogging, especially after wintery autumn rains, surface crusting and difficulties in tilling the soil. In years where crop irrigation has not been needed, a decrease in yields from the irrigated areas (pivot circle) were observed compared to the non-irrigated areas (corners); this observation leads us to infer that irrigation caused soil degradation.

The increase in the soil's ESP produces dispersion and expansion in the clays within the soil matrix. Expansion reduces the size of the

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pores in the soil while dispersion clogs the pores due to the migration of small particles; both phenomena lower the *K* (Costa et al., 1991; Frenkel et al., 1978; Shainberg and Letey, 1984). Expansion is not noticeable until the ESP exceeds 3% (Shainberg and Caiserman, 1971). In contrast, dispersion can take place at an ESP level as low as 2% if the concentration of electrolytes is less than 1 mmol $_{(c)}$ $l^{-1}$ (Felhendler et al., 1974; Shainberg et al., 1981a). Although the content of the electrolytes in irrigation water in HP (5–15 mmol $_{(c)}$ $l^{-1}$) can keep the soil flocculated, when rain water infiltrates the soil it dilutes the concentration of electrolytes and, as a result, causes the expansion and dispersion of clays even at ESP levels that are under 2% (Sumner and Naidu, 1998). The sodium, as well as dispersing the clays, disperses the organic matter (OM), destroying the aggregates in the soil (Crescimanno et al., 1995) and altering the water dynamics in the soil (Abrego et al., 1998). The compaction and breakage of the soil heightens the adverse effects of the sodium (Frenkel et al., 1978). Water infiltration rates, soil dry-aggregation and wet-aggregate stability were negatively affected by changes between irrigation water and rain water, according to most of the documented cases (Pilatti et al., 2006).

Most of the published results on the impact of sodium on the K of soil have been obtained in laboratory studies with disturbed samples (McIntyre, 1979; McNeal and Coleman, 1966; Suarez et al., 1984; Frenkel et al., 1978). There is a very limited set of data to establish the impact of rain water in combination with irrigation water on soil porosity and thus the flow of water in the soil. The criteria for water classification under supplementary irrigation must consider the resultant effect of subsequent rainfall (Suarez et al., 2006).

Our hypothesis is that the amount of irrigation water applied to the soil of a determined SARw, in combination with the amount of rain water, controls the SARe. This SARe value gives the soil the sodic characteristics that can be measured by physical parameters of soil such as K. The objective of the present study is to establish irrigation water suitability criteria under conditions of combined rain and irrigation. To establish this criteria, we measure the impact of rain water and sodium bicarbonated irrigation waters on soil K using field and laboratory studies.

## 2. Materials and methods

### 2.1. Field sites

The trials were carried out on six irrigated plots that we shall call study locations (SL). To validate the information collected, another five plots were chosen, which we shall call validation locations (VL) (Table 1) (Fig. 1). The soil series belonging to the irrigated plots cover a surface area of approximately 25,000 km$^2$ (INTA, 2011). The history of irrigation applications and annual rainfall distribution in the past four years is provided in Table 2.

### 2.2. Soil physical analysis.

The $\delta_b$ and *K* were measured in all the SLs. Each location had a history of supplementary irrigation over more than four years. The irrigation water varied in ECw and SARw values (Table 3).

Measurements of *K* at different water tensions (h) (*K*(h)) were taken at the end of winter, after the ground had been soaked by the end-of-summer and autumn rains. The end of winter and beginning of spring is the time when farmers find it most difficult to work the land. In each location, the circle corresponding to a central pivot was divided up into four equal parts. In each quarter an irrigated section (IS) and a non-irrigated section (NIS) were established with two subsamples point (Fig. 2), totaling 16 sampling points, 8 with irrigation and 8 without. From each of the 16 sampling points 15 subsamples were collected, in a composite soil sample, at a depth of 0–10 cm in each position where electrical conductivity was measured for chemical analysis.

The *K*(h) in the field was measured with a tension infiltrometer with a 20 cm base (Soil Measurement System®), at −140, −80 and −20 mm of h and readings were made over 40 min at each tension, beginning with −140 mm. Wooding (1968) proposes the following equations to describe the three-dimensional movement of water under a disk:

$$K(\mathrm{h}) = K_0 \exp(\mathrm{h}\alpha) \tag{1}$$

$$Q_S = \frac{1}{4}\pi r^2 K_0 \left(1 + \frac{4}{\pi r \alpha}\right) \tag{2}$$

where, $Q_s$ is the flux velocity expressed in m$^3$ s$^{-1}$, r the radius of the disk in mm, $K_0$ the saturated hydraulic conductivity in cm h$^{-1}$, *K*(h) the hydraulic conductivity at tension h in mm, and α is a constant. Using Eq. (1) and the procedure proposed by Logsdon and Jaynes (1993), we managed to calculate $K_0$ and *K*(h). At each of the 8 sample points, we placed two disk infiltrometers, meaning a total of 16 infiltration measurements were taken in each location –8 in irrigated and 8 in non-irrigated fields (Fig. 2). In all cases, rain water was used to take the infiltration measurements.

The $\delta_a$ was measured using the cylinder method (Blake and Hartge, 1986), with 12 samples taken at a depth of 3–8 cm at each sampling point.

### 2.3. Chemical analysis

Chemical measurements of the soil were taken in the SL and in the VL. From each of the 16 sample points at each location, 15 sub-samples were taken in a composite soil sample. These sub-samples were mixed thoroughly and one pint saved for chemical analysis.

The chemical measurements taken were: ECe, pH, soluble ions in the saturation extract (Rhoades, 1982); Cation-exchange capacity (CEC) (Chapman, 1965) and exchangeable cations using the ammonium acetate (pH 7) saturation method and then displacement with sodium acetate (Thomas, 1982); $Ca^{++}$ and $Mg^{++}$ were read with an atomic absorption spectrophotometer (Shimazdu AA 6200®) and $Na^+$ and $K^+$ with a flame photometer (Coring 410®). The soil sodium adsorption ratio (SARe) and water sodium adsorption ratio (SARw) was calculated from the concentrations of $Na^+$, $Ca^{++}$, and $Mg^{++}$ as follow:

$$\mathrm{SAR} = \frac{\mathrm{Na}^+}{\sqrt{\mathrm{Ca}^{++} + \mathrm{Mg}^{++}/2}} \tag{3}$$

### 2.4. Statistical analysis

The statistical mixed model involved the factorial design with location as a random factor and treatment (IS and NIS) as a fixed factor. Hydraulic conductivity at different water tensions was treated as repeated measurements using PROC MIXED (SAS Institute Inc., 2002). The treatment mean comparisons were evaluated using LSMEANS at a significance level of 0.05.

## 3. Result and discussion

### 3.1. Effect of irrigation water quality on soil chemical properties

The ECe showed significant differences between SL, treatments and interaction between locations by treatment (Table 4). The interaction between location and treatments implies there may be differences between the treatments effect at some locations, while a treatments effects is absent at others. Consequently, one should