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*Full Length Research Paper*

# Irrigation with saline-sodic water: Effects on soil chemical-physical properties

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**The results of a two-year research, aimed at studying the effect of irrigation with saline and sodic water on soil physical and chemical properties, are reported. Bean and capsicum were grown in pots filled with two different clay-loam soils, irrigated with 9 types of water obtained from the factorial combination of three salt concentration levels (0.001 – 0.01 – 0.1 M for bean, and 0.01-0.032- 0.1 M for capsicum) with three sodium adsorption ratio (SAR) levels (5, 15 and 45) and were subjected to two leaching fractions (10 and 20%). The results did not show any significant effect of irrigation water's salinity and sodicity, and of the leaching fraction, on soil type. The use of irrigation water with 0.1 M salt concentration caused an increase in electrical conductivity (ECe) from an initial average value of 0.71 dS $m^{-1}$ to 13.9 and 19.5 dS $m^{-1}$, at the end of the first and the second irrigation season, respectively; small variations were, instead, observed, for soil pH. Despite the use of leaching fractions, any increase in the salt concentration and SAR of irrigation water resulted in an increase in the exchangeable Na percentage and a decrease in the exchangeable K, Ca and Mg.**

**Key words:** Soil type, sodic-saline water, leaching, exchangeable sodium percent (ESP), soil aggregates stability.

## INTRODUCTION

Soil salinization and sodification have been identified as major causes of land degradation. Postel (1996) reports that salt-affected areas increase at a high rate, by about 2 million hectares per year. Secondary salinization is the consequence of a not optimal irrigation water management and of the use of saline water for irrigation. This problem is particularly critical in arid and semi-arid regions where total water availability is limited and good quality water is addressed to high-valued uses, and thus poor quality waters, including wastewaters (Minhas et al., 2007; UNESCO, 2003), is often used for irrigation (Richards et al., 1954; Szabolcs, 1989; So and Aylmore, 1993; Tedeschi and Dell'Aquila, 2005). Particularly, if this concerns domestic wastewater, it may have high Na-concentrations resulting from the salt content of human food (Tedeschi and Menenti, 2002; van der Zee et al., 2010).

The problems related to the use of highly saline water affect above all the desert areas in Southern America; some states of the U.S.A: such as California, Arizona (Ayers and Westcot, 1985); many Asian regions, including Pakistan, India, Bangladesh, China, Japan (Levy et al., 1988); the Middle East, the areas between Tigris and Euphrates (Iraq), Bahrain (Ayers and Westcot, 1985); the Negev Desert (Israele) (Pasternak and De Malach, 1987) and the Mediterranean region (Levy et al., 1988). The problem does also exist in Italy, especially in Central-Southern areas, where groundwater is the main source of water supply. As a consequence of the water table drawdown, caused both by its continuous and intensive exploitation and by the low rainfall recorded over the last decades, a significant increase in the salt content of water occurs especially in coastal areas, thus causing a further deterioration of the existing conditions (Graifenberg et al., 1993; Postiglione et al., 1994).

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The major problem of irrigating with saline water is not actually the crop response to irrigation (which is a basically short-term effect) but rather the long-term changes on soil properties that might seriously alter its fertility.

The risk of soil fertility degradation depends both on the total salt content of irrigation water and on the salt composition, especially in relation to Na concentration.

Soil sodification refers to the accumulation of Na, in relation to divalent cations (mainly Ca and Mg), in the soil solution and at the cation exchange complex and may induce severe structural degradation in loamy and clayey soils that contain swelling minerals (Bresler et al., 1982), as consequence of clay particle dispersion. Among physical parameters, the soil aggregates stability index can be considered a good indicator of the soil quality status as function of the agronomic practices adopted (Manachini et al., 2009). Soil fertility degradation depends on irrigation water quality and on soil physical properties as well, with particular regard to clay mineral characteristics (Cavazza et al., 2002).

The de-flocculating effect of sodium ion on clay increases with the concentration of adsorbed sodium; the critical level of exchangeable sodium percentage (ESP) is usually taken as 15% of the cation exchange capacity, although in some soils the sodification characteristics occur at much lower values (Murray and Quirk, 1990).

If ESP becomes too large (e.g. over 15%), the hazard of organic and inorganic colloid dispersion upon introducing good quality water (such as rainwater) increases. Swelling, compression of larger pores, and a severe and often irreversible reduction of hydraulic conductivity can be the result (So and Aylmore, 1993; Halliwell et al., 2001). Since the development of soil sodicity is gradual, and often irreversible within limits imposed by reasonable time scales and costs, it is essential to anticipate its onset. Unfortunately, relatively simple conceptual tools such as the leaching requirement for salinity control (Richards et al., 1954; Howell, 1988; Corwin et al., 2007) are not available for sodicity control. The analysis of the evolution of soil chemical and physical properties, as consequence of supplying water characterized by different total salt concentrations and type, could aid to a better understanding of processes involved and to the definition of tools and land managements able to reduce the soil degradation risk.

Therefore, to provide additional insight into this issue, a two-year research has been performed at Bari University (Italy) with the aim of assessing the effects of irrigation with saline and sodic water on physical and chemical properties of two contrasting soils.

## MATERIALS AND METHODS

The research was carried two-year period at the Campus of the Agricultural Faculty of Bari University (Italy) on bean (*Phaseolus vulgaris* L.) and capsicum (*Capsicum annuum* L.) successive crops, grown in cylindrical pots of 20 and 100 cm respectively in diameter and height, supplied with a bottom valve to collect drained water, and located under shed to prevent the leaching action of rainfall.

In both years, thirty-six treatments obtained from the factorial combination of two not saline soil types with nine types of water and two leaching fractions (10 to 20%) were compared.

The soils were clay loam; the first (T1) was poor in iron and aluminium sesquioxides, non calcareous, taken from the AP horizon of a *Udertic Ustochrept* fine, mixed mesic, series Montefalcone on the Emilia-Romagna soil map, northern Italy; the second (T2) contained more kaolin, it was calcareous and rich in sesquioxides, taken from the AP horizon of a *Pachic Haploxeroll,* fine mixed, thermic, series *Cutino* on the Apulia soil map, southern Italyn (Table 1).

The nine types of water were obtained by dissolving adequate amounts of NaCl and $CaCl_2$ in de-ionised water, and from the factorial combination of three salt concentration levels (0.001- 0.01 - 0.1 M for bean irrigation in the first year; 0.01 – 0.032 – 0.1 M for capsicum irrigation in the second year) with 3 SAR (sodium adsorption ratio) levels (5 - 15 - 45) (Table 2).

A split plot design with two replicates was used, with the two soil types in plots (18 pots), the two leaching fractions in sub-plots (9 pots) and the nine types of water in sub-sub-plots (single pots). As concerns, the fat round bean, cv. Taylor's Horticultural, just after sowing several water applications were effected using the compared different types of water to favour seed germination and plantlet emergence, which occurred 15 to 20 days after sowing. For capsicum (cv. Argo) just after transplantation, plantlets were instead irrigated with de-ionised water till rooting. Just after bean emergence and capsicum plantlet rooting, irrigation was applied whenever 30% of the maximum available moisture was lost by evapotranspiration. The amount of irrigation water corresponded to the volume required to restore the field capacity in the whole soil mass contained in each pot, plus the leaching fraction.

Through the cropping cycles, the water drained from each pot was collected and analysed for the leached solutes.

To characterise the soil at the end of the cropping cycle both for fat round bean and capsicum, for each pot (when it had lost 30% of the maximum available moisture) soil samples were taken from the upper layer (0 to 30 cm) for the following determinations:

1. Electrical conductivity and pH of the saturation extract, soluble bases (Na, Ca, Mg), SAR;
2. Exchangeable cations (Na - K - Ca - Mg), exchangeable sodium percentage.

After the two years of irrigation with saline-sodic waters, the soil stability has been evaluated on average samples collected along the whole profile, after separating the soil aggregates ranging between 1 and 2 mm diameter and using wet sieving with vertical oscillation, with or without alcohol pretreatment (Hénin et al., 1969; Kemper and Rosenau, 1986). The tests of stability of the aggregates allow differentiating soils according to their physical properties, but little is known about the relationship between indicators of aggregate stability and soil response to specific destabilizing factors.

All data were then submitted to analysis of variance using the SAS software (S.A.S.INSTITUTEINC.-USA), and the differences between the means were assessed by the Student-Newman-Keuls test; the most significant ones are reported in Figures 1 to 7.

## RESULTS

In the adopted watering regime, the irrigation variables were equal for both soil types being compared but varied

**Table 1.** Main properties of the soils being tested.

| Parameter | T1 | T2 |
|---|---|---|
| **Chemical properties** | | |
| Total nitrogen (Kjeldahl method) (g kg$^{-1}$) | 0.79 | 1.65 |
| Available phosphorus (Olsen method) (mg kg$^{-1}$) | 31.50 | 52.50 |
| Exchangeable potassium ($BaCl_2$ method) (mg kg$^{-1}$) | 160.00 | 352.00 |
| Organic matter (Walkley Black method) (g 100 g$^{-1}$) | 1.21 | 3.13 |
| Total limestone (g 100 g$^{-1}$) | 0.47 | 2.58 |
| Active limestone (g 100 g$^{-1}$) | 0.05 | 1.40 |
| pH (pH in $H_2O$) | 6.80 | 6.90 |
| ECe (dS m$^{-1}$) | 0.65 | 0.78 |
| ESP | 0.70 | 0.80 |
| CEC ($BaCl_2$ method) (meq 100 g$^{-1}$ of dry soil) | 29.54 | 31.61 |
| **Particle-size analysis** | | |
| Total sand: 2 > ∅ > 0.02 mm (g 100 g$^{-1}$) | 30.27 | 20.94 |
| Silt (%): 0.02 > ∅ > 0.002 mm (g 100 g$^{-1}$) | 33.10 | 44.00 |
| Clay (%): ∅< 0.002 mm (g 100 g$^{-1}$) | 33.63 | 35.06 |
| **Hydrologic properties** | | |
| Field capacity (field determ.) (g 100 g$^{-1}$ of soil dry mass ) | 34.50 | 35.80 |
| Wilting point (-1.5 MPa) (g 100 g$^{-1}$ of soil dry mass ) | 14.70 | 18.40 |
| Bulk density (t m$^{-3}$) | 1.20 | 1.20 |

**Table 2.** Salt concentration, sodium adsorption ratio (SAR) and electrical conductivity (ECw) of the irrigation water compared.

| Bean | | | Capsicum | | |
|---|---|---|---|---|---|
| Salt concentration (M) | SAR | ECw (dS m$^{-1}$) | Salt concentration (M) | SAR | ECw (dS m$^{-1}$) |
| 0.001 | 5 | 0.13 | 0.01 | 5 | 1.47 |
| 0.001 | 15 | 0.12 | 0.01 | 15 | 1.24 |
| 0.001 | 45 | 0.12 | 0.01 | 45 | 1.19 |
| 0.01 | 5 | 1.47 | 0.032 | 5 | 4.65 |
| 0.01 | 15 | 1.24 | 0.032 | 15 | 3.86 |
| 0.01 | 45 | 1.19 | 0.032 | 45 | 3.59 |
| 0.1 | 5 | 13.55 | 0.1 | 5 | 13.55 |
| 0.1 | 15 | 11.18 | 0.1 | 15 | 11.18 |
| 0.1 | 45 | 10.20 | 0.1 | 45 | 10.20 |

according to the quality of applied water. The number of waterings and the seasonal irrigation volumes supplied to each pot based on evapotranspiration, decreased as the irrigation water salinity and SAR increased, due to the smaller plant development. On average, the seasonal irrigation volumes per pot decreased as the salt concentration of the irrigation water increased, respectively with leaching fractions of 10 and 20% of the watering volume, from 35 to 13 L and from 40 to 16 L for bean, from 67 to 56 L and from 75 to 64 L for capsicum. Even the solutes supplied to each pot varied as a function of the quality and quantity of applied water (Figure 1).

In particular, with 10% leaching fraction, applied solutes were, 10.2 and 204 mg/100 g of soil dry mass respectively, for bean and capsicum when irrigated with water of lower salt concentration, and 484 and 1476 mg/100 g of soil d. m. when irrigated with water of higher salt concentration; with 20% leaching fraction, instead, the applied solutes were 11.9 and 228 and 554 and 1595 mg/100 g of soil dry mass (Figure 1), respectively, for the waters of lower and higher salt concentrations.

The amounts of water drained from each pot were

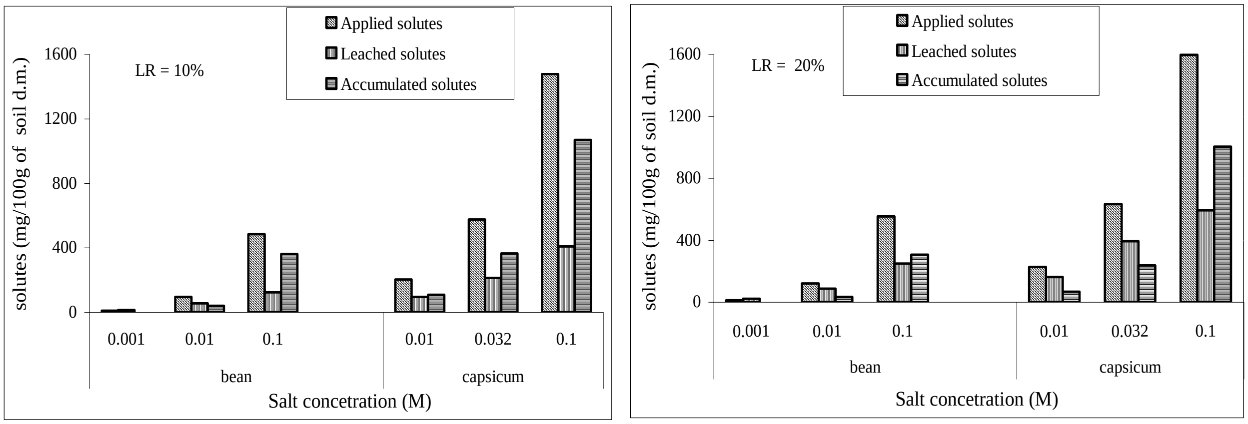

**Figure 1.** Applied, leached and accumulated solutes in the soil irrigated with water of different salt concentrations and subject to two leaching fractions in t bean and capsicum end of the cropping cycle. For each effect considered, the values followed by the same letter are not significantly different, according to the SNK test at P ≤ 0.01.

proportional to the applied leaching fractions; the amount of leached solutes, in turn, varied as influenced by the quantity and concentration of drainage water. As a consequence, the leached solutes changed, on average, from the lowest to the highest salt concentration, with LR = 10%, from 14 to 123 mg/100 g of soil dry mass for bean and from 94.5 to 407 mg/100 g of dry mass for capsicum; instead with LR = 20%, it varied from 21 to 248 mg/100 g of soil dry mass for the crop and from 162 to 592 for the crop (Figure 1). From the balance between applied and leached salts it was found that, irrigating bean with water of lower salt concentration (0.001 M) for both leaching requirements (10 and 20% of the watering volume), leached solutes were lower than solutes applied through irrigation water; on average, the loss was 6.6 mg/100 g of soil dry mass. For the pots irrigated with water of higher salt concentrations (0.01 and 0.1 M for bean and 0.032 and 0,1 M for capsicum), instead, accumulated salts were, on average, 36 and 334 mg/100 g of soil dry mass after bean and 300 and 1035 mg/100 g of soil dry mass after capsicum (Figure 1). In both years, no marked differences were observed in terms of amounts of leached solutes varying the leaching fraction from 10 to 20% of the watering volume. As a result of the salt balance, the EC values of the saturation of the top layer soil, 30 cm deep, extract at the end of the 1st and 2nd irrigation seasons respectively, increased, on average, from 1 and 2.2 dS·m$^{-1}$ for the soils irrigated with water of lower salinity level to 2.1 and 4.3 dS m$^{-1}$ and to 13.9 and 19.5 dS m$^{-1}$ for the soils irrigated with waters of intermediate and higher salt concentrations (Figure 2).

With the different SAR values of irrigation water (5 - 15 - 45), the electrical conductivity of the saturation extract (ECe) varied respectively from 5.9 to 5.5 and 4.2 dS · m$^{-1}$ in the 1st year, and from 8.7 to 8.4 and 7.9 in the 2nd year (Figure 2).

Slight modifications were, instead, recorded for the pH of the soil saturation extract, which ranged between 7.4 and 8.1, respectively, using waters of increasing salinity levels and SAR (Figure 3).

With the increase in irrigation water salt concentration, the exchangeable Na gradually increased whereas the exchangeable K, Ca and Mg did not vary significantly, as shown in Figure 4

With the increase in the SAR of irrigation water, the exchangeable Na and, to a lower extent, the exchangeable Mg increased, whereas the amounts of exchangeable K did not vary significantly (Figure 5).

As a result, the exchangeable sodium percentage increased with the increase in the salt concentration and SAR of irrigation water (Figure 6). The SAR of the soil saturation extract was closely correlated with the exchangeable sodium percentage.

Specifically, exchangeable sodium percentage (ESP), as average of the whole soil profile, consistently increased to the increase of the salinity of the water used and, in any case, to the raise of the SAR value. Increasing ESP values worsen soil structure; in the red soil (T2), rich in organic matter, soil structure remains more stable (stability index = 38.8%); this behavior is not observed in the gray calcareous soil (T1) (stability index = 38.8%) (Figure 7).

Illite and caolinite play an important role in stabilizing soil structure especially in soils rich in sesquioxides (Cavazza et al., 2002). In both soils, to the increase of salt concentration of the irrigation water, the trend of the soil aggregates stability indices reflected the ESP level. The structural aggregates stability index decreased on average of more than 12% passing from soils previously irrigated with water having a salt concentration of 0.01 M to those irrigated with water characterized by a salt concentration of 0.1 M (Figure 7). To the low structural stability of not pretreated samples corresponded a higher stability after alcohol pretreatment (Figure 7). The first result represents the conditions at soil surface (effect of rain), while the second better indicates the effect under

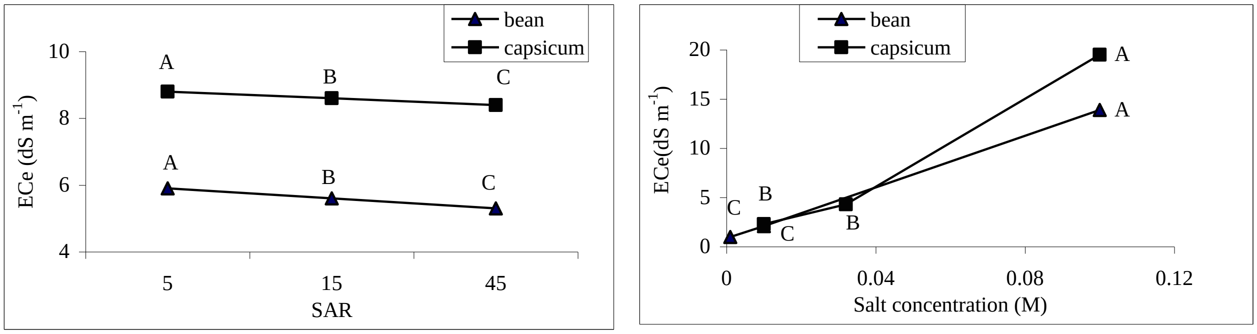

**Figure 2.** Electrical conductivity of the saturation extract (ECe) of the layer soil, 30 cm deep, versus the salt concentration and sodium adsorption ratio (SAR) of the solutions used for irrigation in bean and capsicum end of the cropping cycle. For each effect considered, the values followed by the same letter are not significantly different, according to the SNK test at P ≤ 0.01.

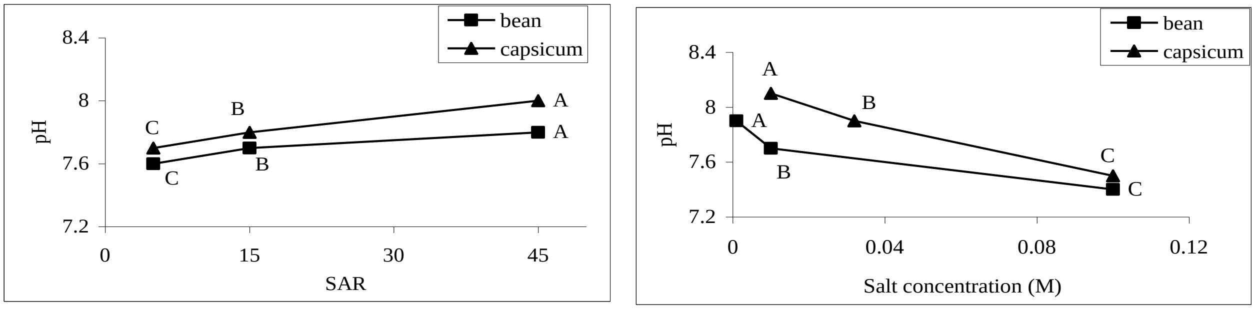

**Figure 3.** pH of the saturation extract of the layer soil, 30 cm deep, versus the salt concentration and the SAR of the solutions used for irrigation in bean and capsicum end of the cropping cycle. For each effect considered, the values followed by the same letter are not significantly different, according to the SNK test at P ≤ 0.01.

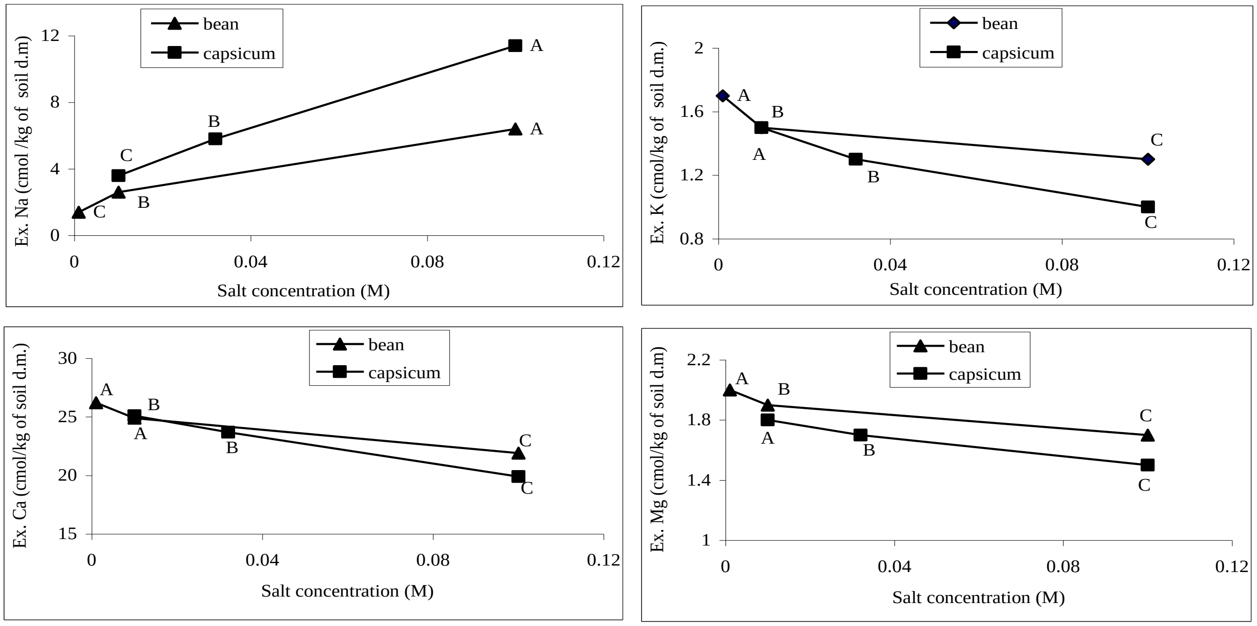

**Figure 4.** Variations of the soil exchangeable bases versus the concentration of the solutions used for irrigation in bean and capsicum end of the cropping cycle. For each effect considered, the values followed by the same letter are not significantly different, according to the SNK test at P ≤ 0.01.

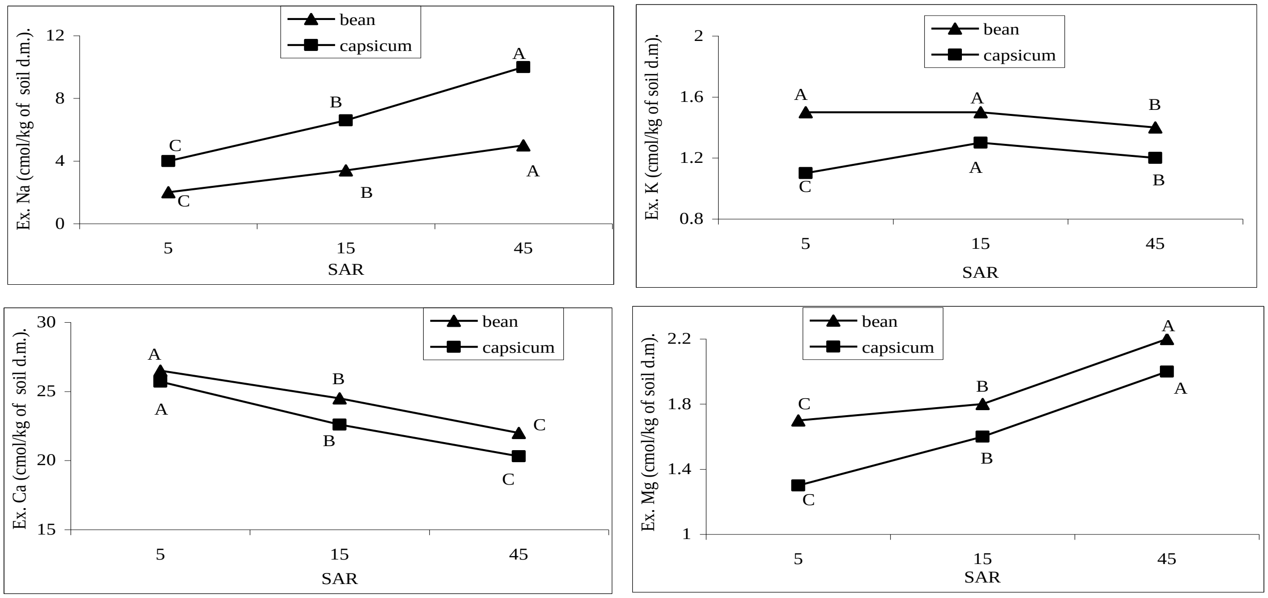

**Figure 5.** Variations of the soil exchangeable bases versus the SAR (Sodium Adsorption Ratio) of the solutions used for irrigation in bean and capsicum end of the cropping cycle. For each effect considered, the values followed by the same letter are not significantly different, according to the SNK test at P ≤ 0.01.

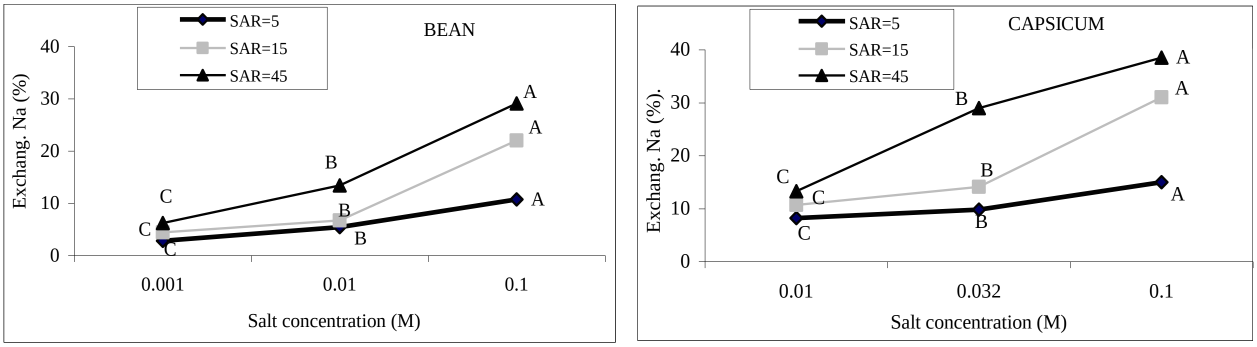

**Figure 6.** Soil exchangeable sodium percentage (ESP) as influenced by the salt concentration and the SAR (Sodium Adsorption Ratio) of the solutions used for irrigation in bean and capsicum end of the cropping cycle. For each effect considered, the values followed by the same letter are not significantly different, according to the SNK test at P ≤ 0.01.

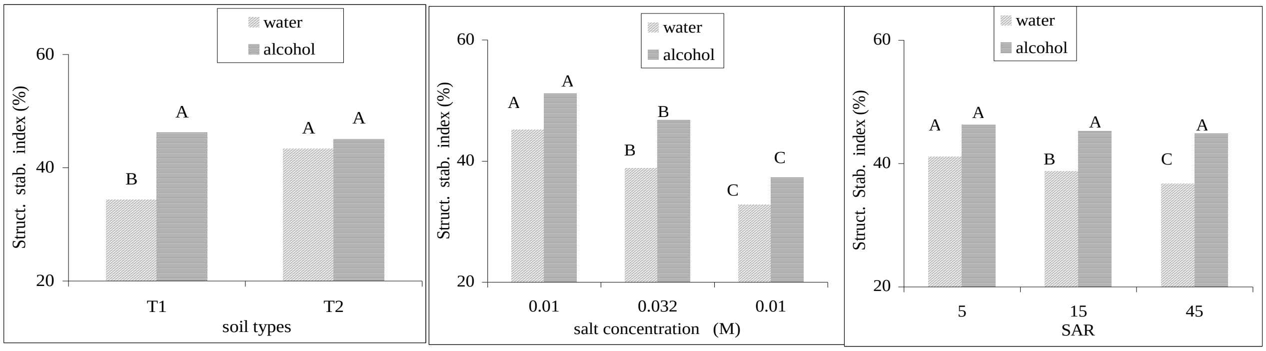

**Figure 7.** Variation of the soil aggregate stability index, with or without alcohol pretreatment as function of soil type, salt concentration and irrigation water SAR. For each effect considered, the values followed by the same letter are not significantly different, according to the SNK test at P≤ 0.01.

the soil surface (Cavazza et al., 2002).

## DISCUSSION

A two-year research was conducted on two soil types, packed in cylindrical pots located under shed, in which bean and capsicum were grown in succession and irrigated with nine types of water, with different salt concentrations and SAR values, and subject to two different leaching requirement levels. The following conclusions may be drawn: The seasonal irrigation volume increased when the leaching requirement (LR) was doubled from 10 to 20% of the watering volume; it decreased, instead, as the salinity of the irrigation water increased. This is due to the fact that salts induced less crop growth and reduced evapotranspiration.

The soil applied solutes increased proportionately to the applied water volume and its salinity. The drainage water volumes were different in relation to the applied leaching requirements. In the first year, because of the soil pore-size reduction, due to soil compaction, and water salinity, drainage water volumes were low, when low and medium salinity waters were used; they were higher, instead, when higher salinity water was used. In the second year, when the salt concentrations of low and medium salinity waters were higher than those of the first year, the drainage water volumes were higher as compared to the applied leaching requirement. The amounts of leached solutes varied with the amount and salt concentration of drainage water. However, with the same amounts of leaching requirements, the leached solute percentage, as compared to those supplied with irrigation water, decreased considerably as the irrigation water salinity increased, with a subsequent reduction of the leaching efficiency of applied water. Therefore, the amount of solutes accumulated in the soil increased as the salt concentration of irrigation water increased; on the other hand, there was a slight variation with the higher leaching requirement and between the two compared soils. The results show that in the Mediterranean areas, where the long-term average yearly rainfall is not less than 450 to 500 mm, winter rainfall could effectively leach the solutes applied with saline water, thus reducing the amounts of irrigation water and the solutes applied to the soil.

As a result of the balance between applied and leached solutes, at the end of the irrigation season of the first and second years, the electrical conductivity of saturation extract (ECe) of the 0.3 m top soil layer, irrigated with the lowest and the highest saline waters, resulted, respectively, equal to 1 and 2.2 $dSm^{-1}$ and to 13.9 and 19.5 $dSm^{-1}$, against an average value of 0.71 $dS\ m^{-1}$ recorded before starting the research. As to the characteristics of the saturation extract by increasing the salt concentration of irrigation water, the pH decreased slightly, while by increasing the SAR, the ECe varied a little and the pH increased. The exchangeable sodium percentage (ESP) increased gradually while the exchangeable calcium percentages decreased gradually as the increasing salinity and SAR of irrigation water increased. The exchangeable potassium percentage did not vary appreciably, and the exchangeable magnesium percentage increased with the rise of the irrigation water SAR.

Soil structure stability index progressively decreased to the increase in soil salinization and sodication in the two soil types. In the red Locorotondo soil, with the clay fraction rich in illite and caolinite, and also in organic matter and iron and aluminum oxides, the structure aggregates remained more stable.

## ACKNOWLEDGEMENTS

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