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Soil salinity changes over 24 years in a Mediterranean irrigated district

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Abstract

Soil degradation from salt accumulation, sodication, or both, is a threat or a fact in many irrigated lands. Salinization has often been assessed from changing cropping patterns over time, and often the trends in salinization have not been quantified. Our objective was to identify trends in salinization or desalinization by direct measurements of soil salinity where a consistent methodology was maintained over time. The soils of the Flumen irrigation district (27,500 ha) in Aragón, Spain, were sampled in 1975. The same plots were sampled again in 1985/1986 and in 1999. There were 140 sampling points in 1975, and 66 in each of the other two surveys. The mean sampling depth was 103 cm, resulting in 909 soil samples and 8603 analytical determinations. Analytical results for salinity, individual ions, and pH retrieved from the first survey were compared with the two subsequent surveys. The electrical conductivity of the saturated extract (ECe) and the sodium adsorption ratio (SAR) of the extract were determined through the soil profiles, allowing us to compare the results from the three surveys. The upper meter of the soil was less saline in 1999 than in 1975. The median ECe of non-saline soils changed only slightly, while in the saline areas the median ECe for comparable soil depths averaged over 1 m was 5.9 dS m^{-1} in 1975, 3.1 dS m^{-1} in 1985/86, and 1.9 dS m^{-1} in 1999. The median of the maximum SAR to the same depth also decreased from 22.0 $(mmol/L)^{0.5}$, to 15.1 $(mmol/L)^{0.5}$, and to 10.5 $(mmol/L)^{0.5}$ for the same three periods. Thus, soil salinity in the upper meter of soil has decreased during the last 24 years.

Keywords: Sodicity; Long-term monitoring; Soil salinity trend; Salt-affected soils

1. Introduction

To assess salinization or desalinization, one must quantify and then monitor the changes in soil salinity over time. This is time and labor intensive at field scales and larger. The seasonal variation of soil salinity, as well as its lateral and vertical variation, complicates the process of surveying. Under irrigation, movement of salts vertically and laterally

Abbreviations: EC, electrical conductivity; compECe, the ECe up to the comparable depth (*D*) for a site and date; compmSAR, the maximum SAR determined for a site and date up to the comparable depth (*D*); *D*, depth of sampling comparable between different years in a given site; EC1:5, electrical conductivity of the 1:5 water-to-soil extract; ECe, electrical conductivity of the saturation extract; ET_0, reference evapotranspiration; MAPA, Spanish Ministry of Agriculture, Food, and Fisheries; PS, percent of saturation; SAR, sodium adsorption ratio; UTM, universal transverse Mercator.

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through the soils is also complicated by changes in water application patterns related to crop rotation. Long-term changes in soil salinity can be qualitatively assessed by archaeological methods (Jacobsen and Adams, 1958; Siyu et al., 1996) or from historic records (Blavia, 1889). Such long-term assessments are made by comparing changes over the years either in natural vegetation or crops in cultivated regions. However, in many agriculturally advanced irrigated districts, such as those common in Spain, changes in soil salinity cannot be traced from the shift to salt-tolerant crops over the years because, apart from soil limitations, the choice of crop by each farmer depends on the anticipated amount of irrigation water available, and on socioeconomic factors.

Parr et al. (2002) have stressed the need for a long-term monitoring program for terrestrial systems in Europe. In some countries, long-term soil studies can be based on existing soil surveys (Young, 1991, 1998). Where such maps are unavailable, other historic data about soils can be used. While the examples presented by Young (1991) are not related to salinity, most of his discussion on the objections and benefits of soil monitoring is applicable to soil salinity, as dependent on land use (Grossman et al., 2001).

Assessments of salinization in the literature are often based on indirect estimation, small-scale studies, or poorly defined periods of time. Some studies of soil salinity change over time are based on soil sampling in agricultural trials conducted on experimental farms for 5 years or less. Such studies are often the only available for extensive tracts of land, being hard to extrapolate and it is questionable whether any long-term trends that could apply to a large irrigated district under commercial management can be established.

Marshall and Palmer (1939) presented comparative measurements for three sites, measuring the soluble ions in soil irrigated for 20 years. Antipov-Karatayev and Pak (1965) monitored the ion content and exchangeable sodium from 1951 to 1960 in two soils. Ballantyne (1978) studied the temporal change in average ECe profiles at a depth of 122 cm for 64 sites, taking one sampling in the fall of each year for 11 years, from 1964 to 1975. The same author (Ballantyne, 1983) presented the soil data for 5 years on twelve 1-ha plots. Chang and Oosterveld (1981), basing their study in part on the work of Marshall and Palmer (1939), studied 10 sites under irrigation for over 60 years and three sites for 25 years. They considered the studied soils to be a representation of several thousands of square kilometers.

Electrical conductivity and pH measured in a 1:1 soil-to-water solution were 2 of the 10 soil properties measured by De Clerck et al. (2003) in their study of the soil quality trends of California soil using paired samples from 115 locations. Their reservations about whether the samples represent the entire 400,000 km^2 that is California can be applied to the work by Lindert et al. (1996), both studies showing the difficulties of a long-term comparison of soil properties.

Other important characteristic of salt-affected soils is the level of Na^+ in the soil system, which affects the behavior of the colloidal fraction of the soil. The level of Na^+ in soil is usually quantified by the exchangeable sodium percentage (ESP) or by its estimator, the sodium adsorption ratio, or SAR (United States Salinity Laboratory Staff, 1954). In the Flumen district, the high SAR values of some soils are attributed to irrigation with water of low electrical conductivity combined with the lack of gypsum in most of the region's soils. Moreover, various cultural practices like puddling or amendments, when carried out over a period of years, can modify the sodicity of the soils. The associated changes in hydraulic behavior are agriculturally and environmentally relevant and can be explained in terms of clay dispersion, which is directly related to the ratio between the ESP and the electrolyte concentration. A detailed appraisal of the effects of high SAR values on the behavior of each soil in our study area should take into account the unfavorable void pattern and the high silt content of some soils (Rodríguez et al., 1990).

In this paper, we add data for 1999 to a previous evaluation of changes in soil salinity for the Flumen irrigation district (Herrero, 1987). For a similar problem, Bitllett et al. (1988) considered two approaches. In the first, many sites are sampled and re-sampled, analyzing the results statistically. In a variation of this technique, previous sites are located, sampled, and reanalyzed. The second approach was used by Herrero (1987) in the Flumen area and is maintained in the present study, incorporating non-parametric techniques of data analysis. This approach allows the variation in soil salinity to be related to local management or other circumstances.