Geoderma xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Soil variability in La Violada Irrigation District (Spain): II Characterizing hydrologic and salinity features

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ARTICLE INFO

Keywords:
Pedotransfer Functions
Available Water Content
Hydraulic conductivity
Soil water balances
Salinity
Gypsum rich soils

ABSTRACT

The recent modernization of 1.1 Mha of irrigated land in Spain calls for the evaluation of these transformations in terms of environmental impact and resource use efficiency. The available data for this evaluation has increased with the transformation (better, digital and spatially distributed data) allowing for the use of distributed soil water and solute movement models. But most hydrological models require soil hydrologic properties that are costly and time-consuming to gather and soil information in Spain is generally scarce. This paper focuses in analyzing the soil hydrologic features in La Violada Irrigation District (VID; a 5234 ha semi-arid irrigated area recently modernized in northeast Spain) usable in soil water models for the evaluation of the new irrigation system.

The recent soil map of the VID (presented in a companion paper) gathered the hydrologic and salinity properties of the horizons in the described soil units. The hydraulic conductivity (K_s) of the horizons was also assessed by the inverse auger-hole method. From these data, the VID was disaggregated in three homogeneous units according to their hydrologic features and Pedotransfer Functions (PTFs) were built for the whole VID (General Model) and separately for the homogeneous soil units (Distributed Model). These PTFs allowed for obtaining field capacity (FC) and wilting point (WP) from texture and organic matter, while K_s depended upon texture and gypsum content.

Apparently, there were no salinity issues in VID soils due to irrigation. The high Ca^{2+} and Mg^{2+} levels in the saturation extract resulted in generally low SAR, what along with the high gypsum and carbonate contents may help to prevent soil degradation by sodicity.

As a result, the homogeneous hydrologic zones defined in VID may be used to recommend specific irrigation practices and as the basis for the application of distributed soil water movement models. These hydrologic properties may be applied directly as inputs to the models while the PTFs may allow for setting adequate parameters in nearby areas with similar soils from more readily available soil information (texture, organic matter and gypsum).

1. Introduction

The first part of this work presented the Violada Irrigation District (VID) soil map and the distribution of the main soil properties in depth and along the VID (thematic maps; Jiménez-Aguirre et al., 2017). Hydraulic conductivity, infiltration and soil water retention are the essential input data for soil water movement models (Minasny and Hartemink, 2011; Nguyen et al., 2015); but the measurement of these properties is a generally complex and time-consuming process (Wagner et al., 2001; Wösten et al., 2001).

Pedotransfer Functions (PTF) provide an alternative to estimate hydrologic soil data [such as Field Capacity (FC), Wilting Point (WP) or

Abbreviations: ANOVA, Analysis of the Variance; AWC, Available Water Capacity; AWUA, Almudévar Water User Association; BD, Bulk Density; CCE, Calcium Carbonate Equivalent; CE, Coarse Elements; dfE, degrees of freedom of the Error; dfT, degrees of freedom of the Total; $EC_{1:5}$, Electric Conductivity of the 1:5 soil-water extract; EC_e, Electric Conductivity of the saturation extract; FC, Field Capacity; GC, Gypsum Content; IRF, Irrigation Return Flows; K_s, Saturated Hydraulic Conductivity; LSD, Least Significant Difference; n, number of submodels from the Distributed Model; N, number of samples; OM, Organic Matter; PTF, Pedotransfer Functions; RMSE, Root Mean Square Error; SAR, Sodium Absorption Ratio; SSE, Sum of Squares of the Error; SST, Sum Squares of the Total; VID, Violada Irrigation District; WP, Wilting Point; WUA, Water User Association

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http://dx.doi.org/10.1016/j.geoderma.2017.04.024
Received 21 October 2016; Received in revised form 7 April 2017; Accepted 26 April 2017

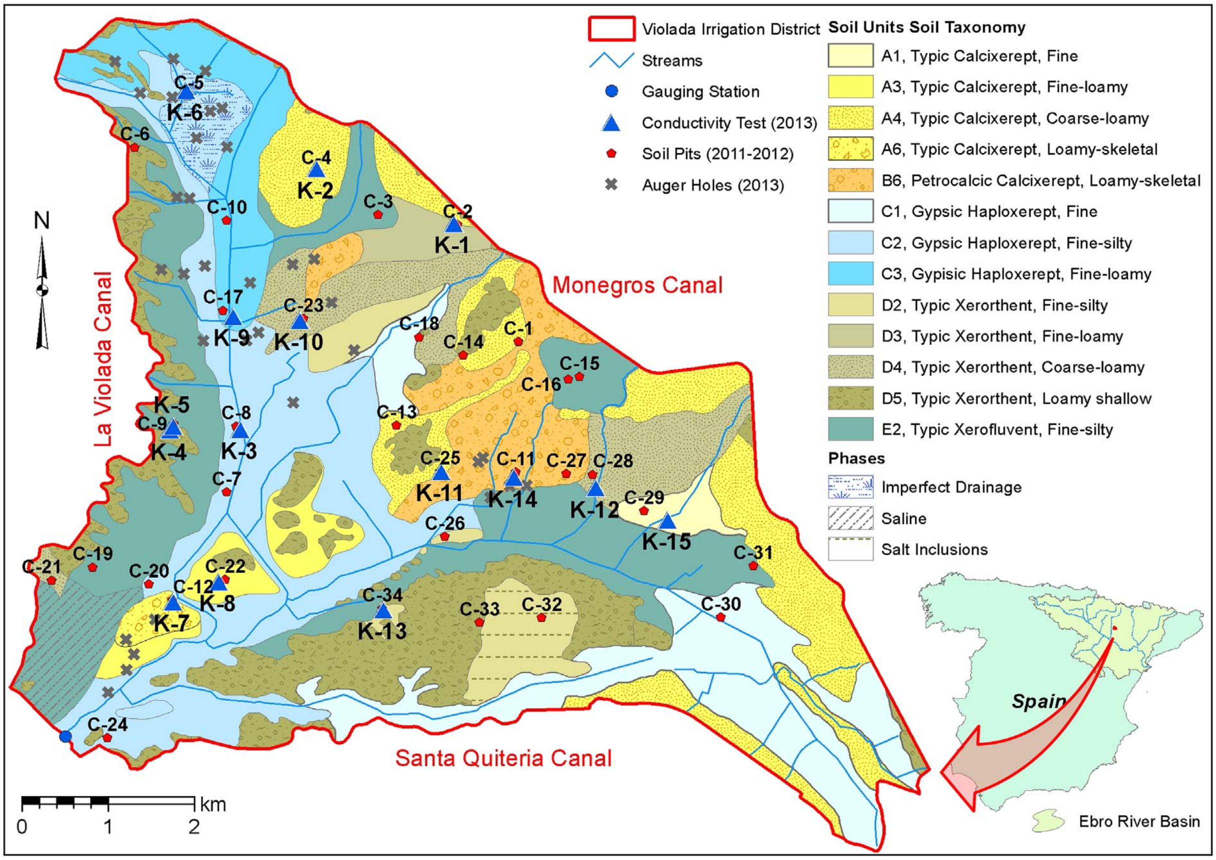

Fig. 1. Map of La Violada Irrigation District: location, irrigation canals, soil map, and observation points [hydraulic conductivity tests (labelled "K"), soil pits ("C") and auger holes (x)] throughout the Violada Irrigation District [from Jiménez-Aguirre et al. (2017)].

Saturated Hydraulic Conductivity (K_s)] from more usual soil survey data as Texture, Organic Matter (OM) or Gypsum Content (GC) (Bouma, 1989; Wösten et al.; 1999, 2001). On the other hand, hydraulic properties, and therefore PTFs, present a temporal and spatial variability with a significant effect on the model results; thus calling for establishing specific, more accurate PTFs for areas with similar soil hydrologic characteristics (Distributed Model) (Franzmeier, 1991; Pachepsky et al., 2006; Wessolek et al., 2011; Wösten et al., 2001).

In Spain, the need for evaluation of the irrigation districts (around 1.1 Mha) recently modernized by the two Nation Irrigation Modernization Plans (MARM, 2002, 2006) is growing. A recently modernized district (2008–09), La Violada Irrigation District (VID), was selected to analyze the impacts of the conversion of a traditional surface irrigation system into sprinkler irrigation.

The VID (5234 ha) is located in the middle Ebro River Basin (Spain), a semi-arid region. VID has been widely studied since the 1980s as described in the companion paper, in regard to agricultural management (crops, irrigation and fertilization) and salts and nutrients loads in the irrigation return flows under traditional irrigation. The new irrigation system in VID, with detailed information about volume and schedule of water applied at hydrant level (Stambouli, 2012) has increased the available information, not only about irrigation, but about fertilization management and crop distribution as well. This calls for the application of distributed soil water models in VID that could yield better estimates of salts and nutrient removal from the district and allow for simulating the effects of plausible future scenarios. And in order to apply such models, better soil information is required.

Developing hydrologic PTFs (FC, WP, K_s) for the whole VID and for smaller homogeneous units with similar hydrological properties, may allow for defining homogeneous hydrological response units, the basis for applying distributed water balance models. These may improve the studies performed in the VID about irrigation return flows, salt and pollutant loads, and water use. In addition, the use of Geographic Information Systems (GIS) permits a higher spatial disaggregation to apply all this information and run models.

Furthermore, the Ebro River Valley is highly vulnerable to salinization (Ibarra, 2004). Salinity is a persistent problem in many irrigated lands in arid and semi-arid regions (Díaz and Herrero, 1992). The risk of salinization or sodification should be checked in a semi-arid irrigated, gypsum-rich area as VID. The secondary salinization affecting irrigated areas has been described (Szabolcs and Várallyay, 1979) using the electrical conductivity of the saturated paste extract (EC_e) or the 1:5 soil-water solution ($EC_{1:5}$) indistinctly as salinity indicators [threshold $EC_e > 4$ dS/m (United States Salinity Laboratory Staff -USSLS, 1954)] for salinity affected soils. However several authors reported the weak correlation between EC_e and $EC_{1:5}$ in soils where GC varies (Aragüés et al., 1986; Casby-Horton et al., 2015; Herrero and Bercero, 1991; Herrero et al., 2009, Moret-Fernández and Herrero, 2015; Nogués et al., 2006).

This work is the second part of an integrated study with the objective of characterizing soil variability (in regard to hydrologic and irrigation related properties) within the VID. Taking as a basis the soil units defined in a companion paper, the specific objectives of this paper are: (i) to define hydrologically homogenous soil zones in the VID; (ii) to define Pedotransfer Functions to link the soil map with soil hydrologic features (FC, WP and K_s) for the homogeneous zones; (iii) to analyze the salinity issues and the risk of salinization in the VID.

The results of this two-part study (combined with distributed irrigation data) could be applied in further modeling works requiring detailed input data or in decision-making processes at water user association (the VID or other irrigation districts with similar hydrological characteristics and scarce soil information) or higher level (such