THE SUCCESS STORY OF IRRIGATION AGAINST SALINITY IN VIOLADA, NE SPAIN

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Abstract

In the early 20th Century, when extensive areas of land were transformed from rainfed to irrigated agriculture there was a severe lack of scientific and technical literature available on the effects of applying water to saline soils. This was the case of the Violada Irrigation District (VID) located in a semi-arid region of NE Spain whose transformation started in the 1940s. We discuss the use of agronomical expertise and the limited knowledge of soils available prior to the transformation, the favorable and unfavorable scenarios encountered during the transformation, and the final success of irrigation despite the initial soil salinization and water logging. We attribute the technical success to the fact that gypsum is common in the soils and geological materials, and to the continued drainage efforts. Failures in the irrigation of saline lands are a frequent subject of discussion in the scientific literature; contrariwise we present the history of a successfully irrigated district after 70 years.

KEYWORDS

agricultural history, drainage, Ebro Basin, gypsum, salt-affected soils.

1. INTRODUCTION

Irrigation, needed for profitable agriculture in arid regions, has been, and continues to be employed, utilizing water from any accessible source. Some ancient peoples, e.g., in Mesopotamia and Lower Egypt, and in other regions around the world (Flannery *et al.*, 1967; Beltrán, 2006; Lang & Stump, 2017; Sandor & Homburg, 2017; Stavi *et al.*, 2017), distributed water for irrigating fields via canal systems. Irrigation by inundation, the only technology available until the mid-20th Century, is still used in many areas around the world where this traditional method of irrigation has led to successful agricultural production for centuries. However, the cases of failure in the sustainability of irrigation in some cultivated areas—or even entire districts with heavy investment in new infrastructure—are globally more frequent than desirable. Soil salinity or/and sodicity, either natural or induced by irrigation, is a common reason for such failures. Irrigation must be managed to leach out the undesirable soluble salts either present in the soil profile or mobilized by water from the parent materials, as well as to avoid soil sodification when the irrigation water has a very low electrical conductivity (EC), as happened in nearby areas (Herrero & Castañeda, 2018). The understanding of the combined effects of EC and sodium adsorption ratio (SAR) on the soil structure became possible based on

the basic research conducted from the 1960s to the 1980s (Sumner, 1993) demonstrating that clay dispersion is more difficult for high salinity levels, especially when gypsum occurs in the soil. In these circumstances the EC will be $> 2.2 \text{ dS m}^{-1}$ and the abundance of calcium ions will avoid the sodium saturation of the exchange complex that would lead to clay dispersion.

Both successes and failures have been seen in the arid regions of Spain, a country where irrigation has been practiced since prehistory (Chapman, 1978). The arid central Ebro valley, in NE Spain, has had irrigated lands for more than 2100 years, as evidenced by Roman inscriptions that display regulations governing a community of irrigators (Beltrán, 2006). Bolea-Foradada (1986) described the irrigation districts in Aragón, central Ebro valley, and provided a great deal of historical data for each of them. The traditional irrigation districts in this region tapped rivers using derivation dams to divert water to the lands along the banks of these rivers. At the beginning of the 20th Century, a new way to irrigate lands in the Ebro valley was initiated, with concrete dams being built across the rivers flowing down from the Pyrenees. These dams distributed water to extensive new irrigation schemes via primary canals that were hundreds of kilometers long, and which fed a network of minor canals that conveyed water to previously leveled fields. One of these schemes is the Riegos del Alto Aragón (RAA), that irrigates 135,300 ha across several irrigation districts, making up one of the biggest irrigation schemes in Europe, with water coming from five main dams built on Pyrenean rivers that can hold 750 million m³ (www.riegosaltoaragon.es). The Monegros Canal was the first built for feeding the RAA project. Alagón-Laste (2013) provides details of the RAA and reviews some of the vicissitudes of its launch. Lecina *et al.* (2010) describe the RAA from an environmental and agricultural point of view, and Villamayor-Tomás (2014) discuss how RAA is managed by cooperation between the irrigators as users of common pool resources.

In the 1940s, the Spanish Government pushed for the irrigation of large tracts of arid land in the central Ebro valley. Under this pressure, the first irrigation districts developed as part of the ambitious RAA scheme. The task was the responsibility of the recently created Instituto Nacional de Colonización (INC), in coordination with the Ebro Basin Water Authority (Confederación Hidrográfica del Ebro, CHE) that was in charge of the design, construction, and operation of the dams and main canals. For this purpose, in 1926 the CHE contracted some of the earliest photogrammetric flights in the world made in peace time (Pérez, 1927; Sada, 1927). The main flights, conducted between 1927 and 1930 (Galván & Losada, 2007), covered the areas dominated by the projected canals in the central Ebro valley; aerial and orthophotographs were obtained after georeferencing.

Some of the new irrigation districts built in dry countries during the mid-20th Century were successful, despite the paucity at this time of technical knowledge to aid in their design and development. The tasks carried out by the agricultural engineers in charge of planning and developing the new irrigation districts included selecting the soils suitable for irrigation, land leveling, advising farmers on the crops to be planted, calculating the volume of water needed by these crops, and designing the plots for basin and border surface irrigation -the only irrigation method available at that time. There were few, if any, guidelines to help accomplish these tasks, but irrigation was urgent. The social circumstances of the early 20th Century in Spain –and specifically in the area of the RAA– were harsh. This explains why Jordana (1921) claimed from the very beginning of the RAA, that irrigable lands were expropriated in the cases

where the owners did not irrigate them within a two-year time period. Such action was permissible under the Law for Large Irrigable Lands (Ley de Grandes Regadíos) passed by the Spanish Government on July 8th, 1911.

This article aims to review the history of the major technical, soil-related challenges the agronomists had to deal with in the Violada Irrigation District (VID) of RAA in order to implement the irrigation works at a time when, across the globe, there was very limited knowledge on land evaluation for irrigation. In order to allow comparison with the historical data, we depict the actual agricultural circumstances of VID.

2. THE DESIGN AND IMPLEMENTATION OF THE RAA

In 1938, the Spanish Government started irrigating the RAA lands close to the origin of the Monegros Canal (Gómez-Ayau, 1957). The Violada Irrigation District (VID) (Fig. 1), with a surface area of 5234 ha (currently about 4000 ha of irrigated land), was the first RAA district to be irrigated. The VID is dominated by the first section of the Monegros Canal, which was ready to transport water in the 1940s; moreover this area is almost flat, with an average slope of < 1%, something that is also reflected in its Latin name *Via lata*, or broad way. Nowadays, the VID is crossed by highway A-23. Most of its surface area belongs to the Almodévar and Tardienta municipalities. The villages of Valsalada, San Jorge, and Artasona (Fig. 1) were built in the district to house the farmers who received the lands newly converted to irrigation.

The water for the VID is taken successively from the Monegros Canal via: (i) the secondary Violada Canal; (ii) several gates off the Monegros Canal; and (iii) the secondary Santa Quiteria Canal, which branches off immediately downstream of the Tardienta Aqueduct (Fig. 1), built in 1941. According to De los Ríos (1966), the Monegros, Violada, and Santa Quiteria Canals were projected with lengths/flows of 142 km/90 m³s⁻¹, 48 km/6.5 m³s⁻¹, and 22 km/1.8 m³s⁻¹, respectively.

In the 1940s the government pressed for the implementation of new irrigation districts but there was very little, if any, literature on how to select lands for irrigation, and neither were there technical guidelines. These drawbacks were magnified by the communication difficulties of the time. This lack of technical references led to the early writing, in Spain, of instructions for the then available irrigation techniques (Pazos, 1951) and guidelines for calculating the water requirements for crops (Tamés, 1950), a necessary task for designing the irrigation districts. Later, the INC conducted experiments to determine the irrigation water needs of certain crops (Álvarez-Peña & Blasco-Escudero, 1965). Formal procedures for studying the soils to be irrigated, and the subsequent selection of land for irrigation, especially under saline and arid conditions, were lacking in the 1940s. The handbook that first established basic concepts and methods relating to soil salinity and sodicity (United States Salinity Laboratory Staff, 1954) came significantly later than the irrigation of the VID and other districts in the Ebro valley.

The document prepared by the US Bureau of Reclamation (USBR, 1951) was probably the earliest most-widely accepted technical manual for classifying land for irrigation, but the VID

and other districts of the RAA were already under irrigation by the time it was published. Other literature on the subject appeared decades later, as shown by references in publications from the Food and Agriculture Organization of the United Nations (FAO, 2007). In particular, the FAO addressed the subjects of soil surveying for irrigation (FAO, 1979) and methods for evaluating land (FAO, 1976; 1985). They also estimated water requirements for irrigated crops with approaches similar to the seminal work of the USBR. In the 1970s, the Instituto de Reforma y Desarrollo Agrario (IRYDA), the successor to the INC, contracted a consulting company to produce a report and soil maps, based on the USBR guidelines (IRYDA, 1978), of 19,939 ha including the VID. Much later, the FAO evaluation method was adapted to another salt-affected irrigated district in the RAA by Nogués *et al.* (2000).

More recently, concerns relating to non-point source pollution and agricultural sustainability have stimulated the modernization of the VID and studies on the hydrology and soils, as well as the design of the refurbished irrigation system, e.g., Playán *et al.* (2000) and Lecina *et al.* (2010). A key step in the modernization has been the change from inundation to pressurized irrigation, which by 2014 was used over 92% of the irrigated surface area of the VID (Jiménez-Aguirre *et al.*, 2018a).

3. SOILS AND IRRIGATION

3.1. The need for irrigation

The VID is semi-arid, with most precipitation falling in spring and autumn. There is an average annual water deficit of 710 mm when comparing the yearly average precipitation of 480 mm with the reference evapotranspiration $ET_0 = 1191$ mm calculated by Faci & Martínez-Cob (1991) using the weather records for a series of 32 years. According to the data from Faci *et al.* (1985), the irrigation water diverted to the VID in the 1982 and 1983 irrigation years was 2.45 times the average precipitation in those years. This type of climate means irrigation is clearly necessary for agriculture to be profitable.

Under rainfed conditions, the climate in the VID only allows for winter cereal-fallow cropping in a two-year rotation, with the yields indicated in Table 1. This poor agriculture, even if supplemented with vineyards and marginal almond and olive trees, forced the emigration of many farmers to urban areas and led to a change in property sizes with a reduction in the number of dryland farms.

3.2. Technical problems at initiation of irrigation

The CHE encouraged the adoption of new crops by establishing a demonstration farm –the Granja de Almudévar– that held a commercial exhibition of agricultural machinery in 1927, and started weather records in 1929. However, the implementation of irrigation in the VID was faced with other technical problems relating to the soils, as shown by >1000 ha that had become marshy in 1940 (Bolea-Foradada, 1986). This resulted in the worsening of land quality immediately after the arrival of irrigation in the plots (De los Ríos, 1966, page 18) either through stagnation or due to the soluble salts brought to the soil surface by

160 evapoconcentration. Some of these problems were unforeseeable in light of the limited
161 technical knowledge available at the time, as discussed in the following paragraphs.

162 In the 1940s, local people were unacquainted with the issues of soil composition and
163 behavior related to irrigation. Only certain toponyms and names of topographic units hinted at
164 the occurrence of areas with possible salinity, water logging, or related problems for irrigation
165 (Alberto & Sancho, 1986). This was the case at those sites with names containing the formative
166 element “sal”, Spanish for salt, such as Salobral and Valsalada; “paúl”, Spanish for an inland
167 marshy site, like Paúles, La Paúl, El Paulazo; and la Fueva, from *fovea*, Latin for depression.
168 Despite the symptoms of the presence and movement of salts in the soil and landscape in
169 general, the planners of the VID believed that salt leaching by irrigation was feasible. They
170 relied on the “good quality” of the water from the Monegros canal, basically from snowmelt
171 with low EC values, but were unaware of the clay dispersion by waters with unfavourable
172 combinations of EC and SAR. The waters of this canal ranging in EC and SAR from 0.32 dS m⁻¹ to
173 0.45 dS m⁻¹, and from 0.3 (meq L⁻¹)^{0.5} to 0.5 (meq L⁻¹)^{0.5}, respectively, (IRYDA, 1978; Barros et
174 al., 2012) could have induced soil sodicity and clay dispersion but luckily these problems were
175 negligible thanks to the gypsum content of the soils that maintains the saturation in Ca²⁺ of the
176 soil solution.

177 3.3. Early land classification

178 A key step in building the irrigation district was the purchase of the lands to be given to
179 the farmers after land systematization, the creation of new leveled plots, and the building of
180 the new canals and roads. A report written by Jordán *et al.* (1951) —presented as Supporting
181 Information 1— illustrates how the land price was appraised. Due to the lack of a soil map and
182 technical guidelines for its preparation, Jordán *et al.* (1951) empirically established five classes
183 of land based on the field reconnaissance of easy-to-recognize soil features such as color,
184 depth, permeability, texture, and so on, in addition to the current yields under rainfed
185 agriculture. Table 1 summarizes these characteristics as estimated by expert judgment. Of
186 course, distances to villages, the road network, and the railway were also taken into account.
187 All this information, together with a survey of the prices of previous private land transactions,
188 resulted in recommended prices to be paid by the Government for the different classes of
189 land.

190 Other land evaluations were made after the VID was fully developed. One of them applied
191 USBR guidelines within the above mentioned study of soils (IRYDA, 1978); another was the
192 evaluation —by crop growth modelling— of the land suitability for maize and barley under
193 irrigation (Faro-Turmo, 1998).

194 3.4. Drainage, a critical issue

195 During the initial years of irrigation (1940-50), some tracts of land suffered from water
196 ponding on the soil surface as mentioned by Jordán *et al.* (1951). Symptoms of water logging
197 can be tracked in the successive editions of cartographic documents. Fig. 2 is a clipping of the
198 photomaps at 1:10,000 scale from 1927 (Galván & Losada, 2007), i.e., before the irrigation,
199 and the same area in 2015. Close to the location of the new Vasalada village, the photomap of
200 1927 shows a waterlogging-prone area, now drained and without salinity problems. The

topographic map at 1:50,000 scale from 1929 (Instituto Geográfico y Catastral, 1929) show no features consistent with water logging in the VID, whereas the 2nd edition of the map produced few years after the irrigation began (Instituto Geográfico y Catastral, 1953) shows a small lake, Laguna de la Fueva, plus several drainage ditches (Fig. 1). The 2010 edition of the same topographic map (Instituto Geográfico Nacional, 2010) shows the same drainage ditches but the lake has disappeared. The LiDAR derived digital elevation model from 2010 shows a closed depression at the location of Laguna de la Fueva, but no signs of water logging appear in the consulted cartographic documents subsequent to 1953.

Opening drainage ditches, the classical procedure for leaching soluble salts and lowering the water table, worked well in the VID and also enabled the water to be reused for irrigation (Alagón-Laste, 2013) with the help of waterwheels that elevated the water from the drainage ditches when needed, and thanks to the acceptable quality of the drainage waters, with average EC of 2.25 dS m⁻¹ and SAR 0.7 (meq L⁻¹)^{0.5} after the measures in the 2000s (Barros *et al.*, 2012). These values are coherent with mean EC of 3.77 dS m⁻¹ and SAR < 2.3 (meq L⁻¹)^{0.5} recorded for phreatic waters 1975 by IRYDA (1978) in Table S1, Supporting Information. The design and installation of drainage systems was a concern for the engineers of IRYDA, as shown by the work of Martínez-Beltrán (1978) in an irrigated area of the central Ebro valley. The excavation of drainage ditches and the installation of subsurface drainage pipes, begun in VID by the INC (De los Ríos, 1966) and continued by the farmers, has resulted in the present-day dense network of drainage ditches and buried pipe drains (Barros *et al.*, 2011b). Barros *et al.* (2012) reported a mean EC of 2.14 dS m⁻¹ at the catchment outflow water for the years 1982-1984, 1995-1998, and 2005-2008, with combinations of EC and SAR allowing the use for irrigation, and stress that “these waters have been regularly used downstream for irrigation without salinity problems”.

The reuse of irrigation effluents, which could have led to soil salinization and sodification, was successful due to the very frequent occurrence of gypsum (CaSO₄•2H₂O) in the soil and parent material, and to the favorable characteristics of the soils with regard to both particle size distribution and mineral composition, which favor salt leaching and impede soil sodification. Jiménez-Aguirre *et al.* (2018a) stress that fine particles and gypsum-rich soils are common along the valley bottoms, while coarser textures and higher calcium carbonate levels are present in the higher reaches. In addition, the high Ca²⁺ and Mg²⁺ contents in the soil solution due to gypsum ubiquity maintain the low SAR, with E_{Ce} < 4.9 dS m⁻¹ and SAR < 4.7 (meq L⁻¹)^{0.5} (Jiménez-Aguirre *et al.*, 2018a, b).

3.5. Soil salinity

Another agricultural problem was the soil salinity related to the occurrence of naturally saline substrates. In dry climates, drought is a greater limitation for agricultural production than soil salinity, so farmers generally do not perceive the latter to be a major problem for their rainfed crops. Soil salinity in the newly irrigated land in Spain was a concern for the INC engineers from at least the 1940s, as shown by the references in Ayers *et al.* (1960). However, the successful desalination of soils in the VID, e.g., in the environs of the new settlement of Valsalada —or “the salty valley” — encouraged the engineers to plan the desalination of other districts by leaching soils with the irrigation water from the Monegros Canal. This method

failed in some areas of the nearby Flumen irrigation district, mainly due to the absence of gypsum in the landscape plus the low electrolyte content of the irrigation water — $EC < 0.4 \text{ dS m}^{-1}$, $SAR < 1 \text{ (meq L}^{-1}\text{)}^{0.5}$ —, as stressed by Nogués *et al.* (2006) and Mora *et al.* (2017), combined with adverse soil hydraulic characteristics (Rodríguez-Ochoa *et al.*, 1990; Herrero & Castañeda, 2018) due to the horizontally microlaminated parent material.

The basin and border irrigation method decreased substantially in the VID due to the gradual adoption of pressurized irrigation over the past 20 years. The far-reaching shift to sprinkler irrigation happened in 2008-09, as shown by the Figure 2, where the photograph of 2009 shows ill-limited plots during the works for changing the irrigation system. If detailed soil maps become available, the way will be paved for a wise use of water based on precision irrigation responding to short-range variations in soil salinity and hydraulic characteristics. These kinds of properties can now be mapped at detailed scales with easy-to-use technologies, as has been done in nearby areas by Nogués *et al.* (2006) and López-Lozano *et al.* (2010).

3.6. How soils affect the stability of water conveying structures

The failures of some public works in the gypsiferous areas of Spain were a concern for civil engineers, as shown by the First International Colloquium on Public Works on Gypsiferous Terrains, held in Madrid, Seville, and Zaragoza in September, 1962, organized by the Spanish Geological Service for Public Works (I Coloquio Internacional sobre las Obras Públicas en terrenos yesíferos. Servicio Geológico de Obras Públicas), whose proceedings were published by Riba & Llamas (1962). The attendants to the Colloquium visited the Violada Canal affected by frequent collapses associated to gypsiferous terrains.

The construction of canals and ditches in the VID was also challenged by the frequent occurrence of significant amounts of gypsum in both the soils and geological materials, due to the way this mineral attacks concrete and iron. The Miocene interbedded lutites with nodular gypsum forming tabular strata (Del Olmo *et al.*, 1995) are very frequent in VID. Sinkholes caused by the dissolution of gypsum and more soluble salts also damaged the first irrigation trenches, as shown by the pictures of collapses in the Violada Canal in 1954, published by Llamas (1958). These canals had to be replaced by aqueducts made with successive precast concrete sections designed so that the joints connecting the sections were not resting on the pillars, to avoid any corrosion or dissolution of the foundations should there be accidental leakage at the joints. The Violada Canal, constructed in the 1930s, had to be rebuilt as an aqueduct in 2002 employing this design, although the Santa Quiteria Canal, built in 1963, had already been designed as an aqueduct (Alagón-Laste, 2013). In the 1960s, the small irrigation ditches conveying water to the plots were specially treated in the gypsiferous sections by lining ditches with polyethylene sheets; this was an expensive material at that time, as reflected in the detailed budget prepared by INC (Blasco-Escudero, 1967).

4. THE PRESENT AGRICULTURAL CONDITIONS IN THE VID

The same engineers that supervised the first steps of the VID, in the 1940-50s, became aware, just a few years later, of the new irrigation technologies. They visited the areas in the

Ebro valley that were pioneering sprinkler irrigation and reported on the pros and cons of the new technology (De los Ríos-Romero, 1967; Supporting Information 2). This has been finally adopted in the VID.

Several authors have studied the hydrological and environmental conditions in the VID after its transformation to irrigation and later modernization (Faci *et al.*, 1985; Barros *et al.*, 2011a, b, 2012; Jiménez-Aguirre *et al.*, 2018b); the change in agricultural management and production in the VID can be illustrated by the water balances established by these authors. Jiménez-Aguirre *et al.* (2018a) have delineated soil units in VID according to Soil Taxonomy (Soil Survey Staff, 2014). These soil units combine: (i) five Subgroups (Typic Calcixerept, Petrocalcic Calcixerept, Gypsic Haploxerept, Typic Xerorthent, and Typic Xerofluvent), (ii) six Particle Size Families (Fine, Fine-silty, Fine-loamy, Coarse-loamy, Loamy Shallow, and Loamy-skeletal), and (iii) three Phases (Imperfect Drainage, Saline, and Salt Inclusions). The modest salinity achieved in the root zone in the sprinkler-irrigated soils is well illustrated by the usual crops (Table 2) with barley—the only one tolerant to salinity (Grieve *et al.*, 2011)—being planted to allow double cropping thanks to its short vegetative cycle.

The very last step in the evolution of agriculture in the VID was marked by the almost general implementation of fully automated pressurized irrigation systems managed by an Association of Irrigators. The main advantages of this strategy are: (i) it overcomes the manpower shortage; (ii) it optimizes water productivity; and (iii) it complies with the environmental regulations on water use and pollution by salts and agrochemicals.

The economic success of irrigation is undeniable if comparing the present yields (Table 2) with those reported in Table 1 for the rainfed crops in 1951. The final socioeconomic balance of irrigation in the VID is highly positive in increasing the farmers' incomes and their quality of life due to the full mechanization of agricultural works including irrigation automatization. The agriculture has changed drastically from the original rainfed crops in small fields (Fig. 2) with winter cereal, some vineyards, and marginal almond or olive trees until the present land systematization with plots sizes allowing competitive agriculture (Fig. 3). Prior to irrigation, years of zero yields were frequent due to the paucity and irregular nature of precipitation and recurrent drought periods; the crop areas reported by Faci *et al.* (1985) were: alfalfa + pastures, 20.7%; corn 19.4%; wheat 58.3%. In contrast, the farmers' declarations for the Common Agricultural Policy in 2016 (Fig. 4), state that the areas of the main crops were at that time: alfalfa, 19.3%; barley, 18.6%; corn, 31.0%; sunflower, 13.0%; and wheat, 11.7%. Irrigation has resulted in the present stable production of diverse crops, and through time there has also been an increase of the more profitable alfalfa and corn.

5. FINAL REMARKS

The planning and accomplishment of the RAA project in the 1940-1950s was carried out despite a lack of scientific knowledge on the soils to be irrigated. This fact together with the absence of suitable generic technical guidelines for selecting lands for irrigation made it impossible to foresee the effects of the abrupt and drastic changes in soil moisture, solutes, and temperature regimes caused by the application of not only the water needed by the crops,

but also that required to keep the salts below the root zone. Some effects of the irrigation were undesirable, but it seems unfair to refer these as mistakes without taking into account the social and technical circumstances of the 1940s. Indeed, the economic success of irrigation was undeniable, as was the corresponding improvement in the human aspects, as described by De los Ríos (1966), for both the new settlers and the pre-existing local population.

The overall agricultural success of the VID and similarly transformed areas can be attributed to the doggedness and hard work of several generations of farmers, and to the large doses of empiricism and common sense applied during the first steps taken in this irrigation district. The approach worked well in the VID, helped by the favorable circumstance of soils that were: (i) mildly saline; (ii) favorable to salt leaching with the available irrigation water; and (iii) resistant to sodification due to the presence of gypsum. The 60+ years of sustained agricultural success in the VID has been also supported by the early adoption of the state-of-the-art irrigation technologies —namely pressurized irrigation— that helped avoid the problem of soil salt accumulation that has occurred in other irrigated lands around the world, and which has helped the agriculture remain profitable.

The historical approach of this Report led us to rescue some rare documents. Hopefully it will reinforce the foundations of forthcoming efforts to incorporate existing and newly collected series of soil salinity data, as was already done for a neighbouring area (Herrero and Pérez-Coveta, 2005) including the overcoming of the constraints due to location accuracy (Herrero *et al.*, 2011). The need for field observation and validation are not replaced by new technologies, but the acquisition of soil salinity data can be quickened by using commercially available sensors (Weindorf *et al.*, 2016). Ideally, the data sets resulting from old documents and present surveys could be incorporated into Land Use and Coverage Area frame Survey (LUCAS) soil survey (Orgiazzi *et al.*, 2018) or to any accessible data base with reliable curation and vocation of permanence. A similar task seems feasible for other VID features such as land use, crop history, hydraulic properties, or salts and agrochemicals outputs.

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525

526 **Table 1. Summary of the characteristics used for diagnosing the Land Classes in the VID, after Jordán de Urriés et al. (1951).**

527

Class	Color	Depth	Permeability	Texture	Slope	Erosion	Total score	Rainfed crop or land use*	Crop yield, kg ha ⁻¹
1	Light brown	Deep	Moderate	Clay-silty, medium	Flat or slightly sloping	No	Favorable	Alternanting wheat/bare fallow	900 to 1100
2	2a) Grayish-brown or light brown	Moderately deep	Moderately slow	Heavy, clay-gypseous dominance	Sloping	Moderately strong; none if terraced	Medium		700 to 900
	2b) Dark brown, light brown, or reddish brown	Deep	Moderate or moderately slow	Light	Slightly sloping	No			
3	3a) Light brown or light gray	No differentiated upper horizon	Slow	Heavy	Sloping or slightly sloping	Moderately strong	Unfavorable medium		500 to 700
	3b) Brown, light brown, or gray	Shallow	Moderately slow	Medium or heavy	Sloping				
4 Gravelly lands	Light brown or light gray	Shallow; frequent Petrocalcic horizons		Very light	Most times sloping or slightly sloping	Strong	Unfavorable	Rotation of bare fallow/rye, or bare/wheat/bare. Economic destination: vineyard	300 to 500

528

5 a Rangeland	Gray or light-gray	Shallow	Very slow (Petrocalcic)	Light or very light	Around 20%	Very strong. Gullies	Unfavorable	Only grazing	
5 b Sandy	Very light gray		Very permeable	Very light	Slightly sloping	Very strong			
5 c Saline	Light brown or gray		Very slow	Heavy	Slightly sloping	Very strong			
5 d Gypseous	Light gray or very light		Very slow		Slope > 5% to 15%				

529 Note. The translation into English is only approximate because the terms were not defined, and most of them are generic or local folk terms.

530 * The original document in Spanish (see Supporting Information 1) reads: Capacidad técnica y económica, i.e., Technical and economical capacity.

531

Table 2. Yields of the most common crops at VID after our survey on the Almodévar Cooperative in November 2017.

Crop	Average yields, kg ha ⁻¹	
	Sprinkler irrigated	Rainfed
Alfalfa	16,000	-
Barley, double harvest with sunflower or corn	6,500	-
Barley, single harvest	-	3,000
Corn	14,000	-
Corn, 2 nd harvest after barley	12,000	-
Sunflower, 2 nd harvest, sown at the end of June	3,000	-
Wheat	6,000	2,500

Figure captions

Fig. 1. Location of the Violada Irrigation District (VID) in the Ebro valley, NE Spain. The white lines are the main gullies and drainage ditches shown on the topographic map of 1953. The ditches and the lake did not figure in the 1929 edition of the map, before the irrigation started. The lake disappeared in the 2010 edition, but the drainage ditches continue to be figured.

Fig. 2. Clips for the area marked at Fig. 1. Left: waterlogging-prone area in the photomap of 1927. Right: regular and well cultivated plots without salinity symptoms in the ortophotograph of 2015. The toponyms El Paulazo “The Big Marshy” and Valsalada “Salty valley” are revealing. White lines are the main drainage courses.

Fig. 3. The sketch of VID is superposed to sequential ortophotographs of “SIG Oleícola” (1997) and Spanish Plan of Aerial Orthophotograph (from 2003 to 2015) along the irrigation times. Many plots show blurry limits in 2009 because of the works in progress for changing to sprinkling irrigation.

Fig. 4. Distribution of alfalfa, barley, corn, sunflower, and wheat in the VID according to the farmers’ declarations for the Common Agricultural Policy in 2016. A total of 3902 ha were declared to be under irrigation and 327 ha declared as rainfed.

Supporting information (in the publisher’s version or in Digital CSIC)

1951 INC Dictamen Jordan de Urries.pdf

1967 INC De los Rios aspersion.pdf