Water saving challenges in a gravity-flow irrigation district. The action of Lis Valley Water Management Operational Group (EIP-AGRI), Portugal

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Abstract. Water savings on an irrigation district is a complex and challenging issue because it should be reached not only keeping the irrigated area, but also increasing farmer's income, with a satisfactory equitable water distribution on the collective network system. Periods of water scarcity are not avoided by gravity-fed conveyance systems supplied by surface water runoff, requiring specific water management practices to optimize equity. This communication presents results of the Lis Valley Water Management Operational Group, integrated on the agricultural European Innovation Partnership (EIP-AGRI). The study aims at monitoring the collective supply network and the on-farm irrigation management, assessing the guidelines and procedures to carry out water savings, in a context of improving the rural development and environmental and economic sustainability. Preliminary conclusions point to priority actions to consolidate improved water management, being the technological innovation an element of the modernization of irrigation districts. This modernization justifies the development of multiple efforts and synergies amongst stakeholders, namely farmers, water users association, and researchers. The Operational Group, in particular, through the monitoring of the conveyance system and the evaluation of the on-farm irrigation, in a deep collaboration with active farmers, provides information and knowledge, enabling WUA to progressively improve district water management.

Keywords: Lis Valley, water management, public collective irrigation, environmental monitoring, rural development.

1 Introduction

Society is urging water savings by irrigated agriculture, through the decrease of water consumption, to cope with global changes and water scarcity problems [1]. Water savings is challenging to maintain or increase agricultural production, and requires the adaptation of irrigated agriculture, through a change of technology and practices compatible with the farmers’ technical know-how and farms economic sustainability [2]. Saving water at collective irrigation districts scale is not fully reconcilable with an equitable water distribution to on-farm fields [3]. Technological irrigation innovations, namely on management process, tend to emerge in response to water scarcity, soil constraints, climate change and also new economic opportunities [4]. On one hand, consumer demand for food products is changing for economic reasons or for the perception of sustainability issues related to production. On the other hand, water management requires the modernization of systems compatible with the overall development of the economy. Irrigation competitiveness results from increased land productivity and control of the effects of climatic variability, but also from the possibility of producing crops with higher added value, such as horticultural crops.

The entrepreneurial competitiveness of the Portuguese agriculture depends heavily on irrigation [5], a situation evidenced by the Value of Standard Production of more than 5000 euros/ha in irrigation and only 800 euros/ha in the rainfed agriculture [6]. This paper presents a study of a gravity-fed irrigation district, the Lis Valley, carried out on the framework of an Operational Group of EIP-AGRI [7], that aims to contribute to Lis Valley rural and environmental development. The overall objective is the improvement of water management, as a result of monitoring at district and on-farm scales. The specific objectives consider the following improvements: performance of collective water supply, effectiveness of water pumping, and safety of crop production due to the practice of reuse of drainage water. The logic of project information is represented on the flowchart of Figure 1. A monitoring framework centred on water and soil use, allows to assess the irrigation and drainage systems and analyse its socioeconomis impacts, generating knowledge. An information system store data and knowledge, making it acessible to WUA decision-makers to improve the irrigation district water management, allowing that this information, through a feedback flow, could be applied by farmers at on-farm level, and by the WUA on the management of the conveyance system.

2 Study site: Lis Valley Irrigation District

LVID is a public irrigation district, located in the Center of Portugal, belonging to the counties of Leiria and Marinha Grande (Fig. 2), and managed by the Water Users Association (WUA). It has a total area of about 2000 ha, the soils are mainly modern alluvial soils of high agricultural quality, but some are subject to poor drainage. The hydraulic infrastructures have the objectives of field drainage defense through slope collectors and valley ditches, and irrigation water supply through several small temporary reservoirs from the Lis River and its tributaries.

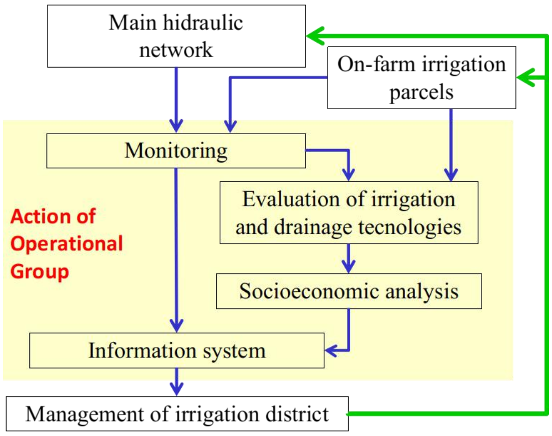

Fig. 1. Information flowchart of Lis Valley Operational Group Project.

Fig. 2. Location of the Lis Valley Irrigation District.

The water conveyance system is subdivided into supply sectors, each one comprising a main canal, gravity-fed by a river diversion from a weir (Fig. 3a,b). Water management is hampered in water running system without upstream reservoirs that ensure the availability of inlet flows, requiring a greater flexibility of distribution on the collective conveyance. During the irrigation peak period, the downstream irrigated areas of some sectors are not fully supplied, being this problem overcome by pumping from the river or drainage ditches. The sectors are the main elements of the system operation by the WUA, which controls the inflow from the weir, the pumping recharge and the distribution to the secondary irrigation network, which consists of small lined or earthen channels to distribute the water to the field hydrants (Fig. 3c) [8]. The water inflow is in general manually controlled, with an active participation of farmers in the establishment of calendars and irrigation times to achieve equitable water partition by on-farm fields.

Fig. 3. View of the irrigation district: a) Arrabalde weir (to supply sectors C1 and C2); b) inflatable weir (to supply sector C7); c) secondary canal and surface irrigated field (sector C7); d) main drain ditch (sectors C4 and C5).

The on-farm assessment of irrigation and drainage practices is of great importance when regarding the general improvement of an irrigation district scale [9]. The dominant irrigation technology in LVID is the surface irrigation, by graded furrow or by flooding level basins, applied essentially to fodder maize and permanent pastures. In some cases, it is characterized by a poor land leveling and water distribution by unlined channel, resulting in reduced efficiency; however, the laser precision leveling is applied in the larger fields, which allows a great efficiency improvement. Pressure systems are becoming of great importance with autonomous pumping. Examples are the drip or microsprinkler, which is the most representative, used for fruit plants, horticultural and nurseries, and sprinkler systems, including pivots, used for corn, meadows and horticulture.The drainage system (Fig. 3d) works on the surface, through the levelling of the ground and the use of open drains, which lead the water to the collective main drainage network.

3 Methods

The monitoring methodology of collective irrigation systems included the observations of operative practices and the measuring of supply discharges, to evaluate the water derived for irrigation and the energy consumed on pumping stations. The affluence to each sector was assesse by the measurement of inflow discharge been applied the canal section-velocity method, where the point velocities were measured with an electromagnetic current meter, brand Valeport, model EM flow meter model 801 flat, and the. The cultivated crop pattern was assessed by farmers inquires. Energy pumping consumed was determine from WUA records. These field measurements follow the procedures presented by Replogle et al. [10]. The water monitoring of convenance and distribution system at sector level allowed to determine performance indicators. The methodology to calculate the Net Irrigation Demand (NID) follows Allen et al. [11], and the one to determine the Total Irrigation Allocation (TIA), summing the Gravity Irrigation Allocation (GIA), with the Pumping Irrigation Allocation (PIA), and the Global Irrigation Efficiency (GIE) was presented by Gonçalves et al. [8].

The methodology for monitoring water quality of irrigation and drainage networks followed the main guidelines proposed by Lothrop et al. [12]. It ensured the spatial representativeness of all irrigation sectors, through the sampling at the main inlet and outlet, and relevant intermediate sites, and also the seasonal irrigation representativeness, including the beginning and the peak periods of the irrigation, drainage, and groundwater. It is worth mentioning that some of sampled sites on the drainage system have a double function: drainage and irrigation. The physicochemical quality of the water samples was evaluated with a precalibrated in-situ portable multiparametric probe (SmarTROLL RDO Handheld, Fort Collins, CO 80524, USA) for the following parameters: Electrical Conductivity (EC, μS/cm), Saturation of Dissolved Oxygen (SDO, %), Temperature (T, ℃), and Total Dissolved Solids (TDS, ppm). Nitrates were also evaluated in the laboratory using ion chromatography. The results obtained were compared to the Maximum Recommended Values (MRV) of the Portuguese Irrigation Water Quality Standards [13]. Microbiological analyses of water samples included the enumeration of Total Coliforms (TC), expressed as the Most Probable Number (MPN/100mL) by the dilution method with the multiple fermentation tube technique and incubation at 37℃ ± 1 ℃ in an appropriate culture medium, in accordance with the analytical reference methods [13].

4 Results

The TIA values of the 2018 irrigation season per sector varied between 6470 m3/ha and 9220 m3/ha (C1A and C2A, respectively), with an average of 7400 m3/ha. The NID values ranged between a minimum on sector C2A (4670 m3/ha), and a maximum on sector C7 (5130 m3/ha), with an average of 4950 m3/ha. The pumping allocation recharge corresponds to 60% in the C1B sector, 10% in sectors C4 and C5, and 7.6% in the C2B sector, with a global average of 9.3% (Figure 6).

The GIE varies between 0.53 and 0.72 (in Sectors C1A, C2A, and C7, respectively), with an average of 0.69 (Figure 6). Generally it can be conclude that the supply was adequate, according to the on-farm irrigation demand, with a satisfactory water distribution equity, as a result of strong collaboration between WUA and farmers. The GIE average value of 0.69 (varying from 0.53 to 0.72) is considered satisfactory [41]. However, this data did not provide enough information to allow splitting this efficiency in the off- and on-farm components. On one hand, the main canals transport efficiency is very variable, sometimes lower than 70%. On the other hand, the observed field irrigation leads to the conclusion that on-farm application efficiency varies between 65% and 90%, according to the irrigation method from the surface to the drip systems. As previously mentioned, major water losses by surface runoff had conditions to be reused downstream. Therefore, these apparent losses became beneficial water use, thus allowing an increased efficiency.

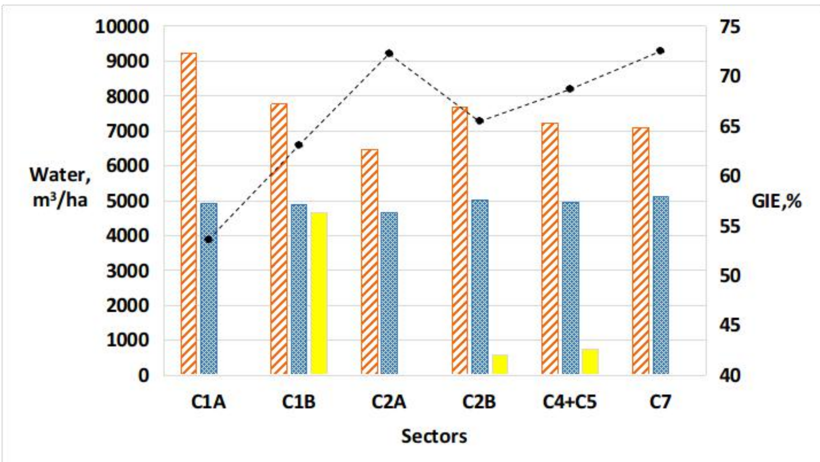

Fig. 4. Total Irrigation Affluence (TIA) ( ), Net Irrigation Demand (NID) ( ), and Pumping Irrigation Allocation (PIA) ( ) in m^3/ha; Global Irrigation Efficiency (GIE, %) ( ); seasonal values per Sector, in 2018 (Source: [8]).

The pH values of water samples from the irrigation, drainage, and groundwater of supply sectors (Table 4) are within an acceptable range [39], in general, slightly above 7.0, except for sectors C4 and C5, whose values are within the range of 6.5–6.9, possibly because this area is supplied by another water source, the Aroeira river, a Lis tributary. The saturation dissolved oxygen (SDO,%) values of water samples (Table

4) were often higher than 50% for drainage, and oftentimes higher than 90% for irrigation.

Table 2. Physicochemical and microbiological parameters of water sampled per sector and water body in 2018 (average ± standard deviation) (Source: [8]).

Sector	Water Body	Water Quality Parameters					
		pH (6.5-8.4)*	EC, µS/cm (1000)*	SDO, %	SDT, ppm (640)*	TC[2]	Nitrates, mg/L (50)*
C1A	Irrigation	7.30	556.0	---	399.5	10.6	---
	Drainage	7.32 ± 0.1	783.7 ± 245.8	59.8 ± 9.5	509.4 ± 159.5	---	---
C1B	Irrigation	7.63 ± 0.1	849.9 ± 100.5	96.4 ± 1.1	552.4 ± 65.2	---	17 ± 2.8
	Drainage	7.32 ± 0.1	783.7 ± 245.8	59.8 ± 9.5	509.4 ± 159.5	---	<6.5
C2A	Irrigation	7.30	556.0	---	399.5	10.6	---
	Drainage	7.54 ± 0.27	620.67 ± 97.6	94.97 ± 7.3	403.9 ± 63.7	13.1	---
C2B	Irrigation	7.54 ± 0.17	753.2 ± 237	96.2 ± 2.2	489.5 ± 154	---	17 ± 2.8
	Drainage	7.52 ± 0.2	558.8 ± 66.8	90.9 ± 6.2	363.2 ± 43.4	1.91	10
C4+ C5	Irrigation	6.66 ± 0.98	494.5 ± 439	92.8 ± 9.1	321.6 ± 286.6	2.70	7.1 ± 1.3
	Drainage	6.84 ± 0.32	972.9 ± 245.4	81.2 ± 5.2	632.9 ± 165.6	7.20	8.6 ± 3.5
	GW[1]	6.52	1472	28.9	959.5	---	9 ± 8.5
C7	Irrigation	7.26 ± 0.3	627.38	88.86	409.58	4.70	---
	Drainage	7.45 ± 0.08	705.3	78.56	458.4	1.15	<3

[1]GW—Groundwater; EC—Electrical Conductivity; SDO—Saturation of Dissolved Oxygen; SDT—Dissolved Solids; [2]TC—Total Coliforms, 10^5 MPN/100mL; ()*Maximum Recommended Values according to the Portuguese Irrigation Water Quality Legislation [13].

Note that, according to Skula et al. [14], though there are no references to irrigation water, it is recommended a value higher than 50% for drinking water, allowing the conclusion that dissolved oxygen in these water bodies is good or acceptable. The very low value for the groundwater sample (SDO = 28.9%) is explained by the local standing water condition on the piezometer. In sectors C1B and C2B, the irrigation water (collected from the Lis river, upstream from the drainage ditches discharge) has a nitrate content of 17 mg/L, whereas in drainage water, these values were below 10 mg/L (Table 4). Sector C7 shows a trace value of nitrates in the drainage network, which might be explained by the dominant cultural system, permanent meadows, with null or reduced nitrogen fertilization. Countering this trend, in sectors C4 and C5, the irrigation water has a lower level of nitrates (7.1 mg/L) than the drainage water (8.6 mg/L), and the groundwater (9.0 mg/L), which is explained by the intensive production system, namely with soil manure amendment. Although the data is still scarce, it indicates that irrigation in the Lis Valley has no significant negative effect on the nitrate load on water resources. A clearer view will be possible when monitoring is concluded and extended to all sectors and quantifying the total nitrogen. The analysis of water microbiological quality, assessed through the TC enumeration at the sector level, shows a spatial variation within the valley. In each sector, TC counts were higher in drainage than in irrigation water, except for sector C7, which revealed a different situation: the TC counts in drainage water were four times lower than that in irrigation water. This might be explained by the soil reducing effect on Enterobacteriaceae numbers and also by a lower soil manure amendment on pastures than in the crops of other sectors. The high TC values of irrigation water of sectors C1A and C2A (Lis river water at Arrabalde weir), and drainage water of sector C2A, is explained by contamination from external sewage sources from the irrigated area. The identification of situations of microbial contamination risk in irrigation water of LVID, whose main responsibility is external to agriculture, requires special precautionary measures, in particular regarding the safety of farmers and consumers. These risks will also need to be assessed for the influence of agricultural activity within the irrigation district, particularly at the drainage network level.

5 Final Considerations

The experimental activity of the project considers the water monitoring, also the soil monitoring and field evaluation of agricultural practices, leading to a better diagnosis of water supply and drainage problems, and improving the quality of operational practices and reducing waste of water and energy. Potential recipients of the activities of the Operational Group are the WUA and farmers, consumers and businesses in the region's agricultural factor trading and processing and marketing industries.

Results point to priority actions to consolidate improved water management: better maintenance and conservation of infrastructure of hydraulic infrastructures to reduce water losses and better flow control; implementation of optimal operational plans, to adjust the water demand with distribution; improvement of the on-farm systems with better water application control and maintenance procedures, reducing labor and increasing the distribution uniformity, applying irrigation scheduling plans based on monitoring systems, using weather stations combined with soil moisture devices or crop remote sensing; and improvement of water quality control on the water reuse from drainage ditches. Technological innovation is an element of the modernization of irrigation districts, which justifies the development of multiple efforts and synergies among stakeholders, namely farmers, water users association, and researchers. The irrigation water management is based on quasi-real-time supply adjustment in the very short time of a few hours or a few days. It is relevant that the relative independence of the supply of several sectors allows the decision-making to be made with higher proximity of the users, creating higher management flexibility. In its turn, cooperation behavior among the group of users at the secondary canal level facilitates the management and favors the equity of water distribution, particularly on the downstream ones. WUA's position of arbitration and regulation is fundamental to guarding and moderating the possible focus of conflict between users. This example meets many cases in which participatory irrigation district management has shown good results.

A conclusion points to priority actions to consolidate improved water management, being the technological innovation an element of the modernization of irrigation district. This modernization justifies the development of multiple efforts and synergies amongst stakeholders, namely farmers, water users association, and researchers. The Operational Group, in particular, through the monitoring of the conveyance system and the evaluation of the on-farm irrigation, in a deep collaboration with active farmers, provides information and knowledge, enabling WUA to progressively improve district water management.

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References

1. Harmel, D., Chaubey, I., Ale, S., Nejadhashemi, A.P., Irmak, S., DeJonge, K.C., ... & Mani, I.: Perspectives on Global Water Security. Transactions of the ASABE, 63(1):69-80 (2020); doi 10.13031/trans.13524.
2. Perry, C., Steduto, P., Allen, R.G., Burt, C.M.: Increasing productivity in irrigated agriculture: Agronomic constraints and hydrological realities. Agricultural Water Management, 96(11), 1517-1524 (2009).
3. Frisvold, G., Sanchez, C., Gollehon, N., Megdal, S.B., Brown, P.: Evaluating Gravity-Flow Irrigation with Lessons from Yuma, Arizona, USA. Sustainability, 10, 1548 (2018); doi:10.3390/su10051548.
4. Backeberg G.R.: Innovation through research and development for irrigation water management. Irrig. and Drain. 63, 176–185 (2014).
5. Silva F.G.: O futuro do regadio numa lógica integrada de gestão de recursos hídricos. AGROTEC, 27, 46–49 (2018) (in Portuguese).
6. INE: Inquérito à Estrutura das Explorações Agrícolas. Lisboa (2017) (in Portuguese).
7. RRN: Grupo Operacional para a Gestão da Água no Vale do Lis. Available online: https://inovacao.rederural.gov.pt/2/81-grupo-operacional-para-a-gestao-da-agua-no-vale-do-lis, last accessed on 2021/02/01.
8. Gonçalves, J.M., Ferreira, S., Nunes, M., Eugénio, R., Amador, A., Filipe, O., ... & Damásio, H.: Developing Irrigation Management at District Scale Based on Water Monitoring: Study on Lis Valley, Portugal. AgriEngineering 2020, 2, 78–95 (2020); doi:10.3390/agriengineering2010006.
9. Replogle J.A., Kruse E.G.: Delivery and distribution systems. In: Hoffman G.J., Evans R.G., Jensen M.E., Martin D.L., Elliot R.L. (Eds.), Design and Operation of Farm Irrigation Systems (2nd Edition), ASABE, St. Joseph, MI, 347-391 (2007).
10. Replogle J.A., Howell, T.A., Solomon, K.H.: Measuring Irrigation Water. In Hoffman J., Evans R.G., Jensen M.E., Martin D.L., Elliot R.L. (Eds.), Chap. 10, 317-370 (1990).
11. Allen R.G., Pereira L.S., Raes D., Smith M.: Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements. FAO Irrig. Drain. Pap. 56, FAO, Rome (1998).
12. Lothrop, N., Bright, K.R., Sexton, J., Pearce-Walker, J., Reynolds, K.A.; Verhougstraete, M.P.: Optimal strategies for monitoring irrigation water quality. Agric. Water Manag., 199, 86–92 (2018).

13. Portuguese Irrigation Water Quality Legislation. Law Decree 236/98, Water Quality Standards, 1998. (In Portuguese)
14. Shukla, A., Shukla, S., Hodges, A.W. Recovering nitrogen from farm-scale drainage: Mechanism and economics Trans. ASABE 2018, 61, 197–206, doi:10.13031/trans.12277.