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EVALUATION OF IRRIGATION SYSTEMS BY USING BENCHMARKING TECHNIQUES

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ABSTRACT Water scarcity, which is typical of arid and semiarid regions such as Castilla- La Mancha (Spain), makes necessary the efficient use of water and energy resources. For this aim, there are several Decision Support System tools, where a benchmarking technique for one of them was established. This technique is based on comparison between management of different Water User Associations (WUAs). The aim of this work is comparison of two of the most extended irrigation systems (sprinkler and drip irrigation systems) in Castilla- La Mancha (Spain), by using performance indicators related to management of irrigated area. The Benchmarking technique was applied during three irrigation seasons (2006-2008) in seven WUAs of Castilla – La Mancha Region (Spain), in which groundwater resources are the most common source of water. The command area of those WUAs is comprised between 170 ha and 1700 ha. The proposed indicators utilized in the Benchmarking techniques are classified into two groups: descriptive and performance indicators. The information required to calculate the proposed indicators as obtained from managers and farmers of each WUA, complemented with data obtained by using specialized equipment. For each irrigation system analyzed (sprinkler and drip irrigation systems) a preliminary analysis by descriptive statistics was performed, with averages and dispersion measures for most of the indicators obtained. In order to establish the grouping and differences between WUAs with different irrigation systems, a Cluster Analysis was applied. The obtained results show a notable difference between WUAs with drip irrigation systems and WUAs with sprinkler irrigation systems. Regarding the energy cost per unit irrigation delivery indicator, there are similarities between WUAs irrigated with sprinkler systems and those irrigated with drip irrigation systems. It can be explained by the fact that all WUAs use groundwater resources. The main differences appeared in total management, operation, and maintenance cost per unit irrigation delivery, in which energy cost are really important. In WUAs with sprinkler irrigation systems, energy cost represent about 65 % of total management, operation, and maintenance cost, compared to approximately 45 % in WUAs with drip irrigation systems.

Keywords: irrigation system, irrigation management, performance indicators, Benchmarking.

INTRODUCTION One of the most important characteristics of irrigated land is that it should be a sustainable activity, together with its economic viability. The increase of water usage might imply a restriction about its availability to be used in irrigated lands.

For that reasons, the efficient use of water by means of the improvement of irrigation management by users is an important issue to develop. This is even more important in regions as Castilla- La Mancha (Spain), where the 90 % of command area (475000 ha) is irrigated by pressure irrigation systems, and in which approximately the 65 % of command area is irrigated by using groundwater resources (Ortega *et al*., 2004). In addition, together with the efficient use of water it is also important to use energy in an efficient manner.

There are many decision support tools that help to make an efficient use of water and energy resources, being one of them Benchmarking technique (Malano *et al*., 2004; Rodríguez *et al.* 2008). This tool is based on the comparison between the management of different Water User Associations (WUAs), trying gain knowledge about their performance.

At first, Benchmarking technique was more extended in business sectors, but in the last years has been used in an important amount of WUAs around the world (Molden *et al*., 1998; Dembele *et al*., 2001; Mondal and Saleh, 2003; Degirmenci *et al.*, 2003; Sodal, 2004). It is based on performance indicators usage, which tries to summarize the information of different WUAs. By using these indicators, it is possible to compare different WUAs (Kloezen and Garcés, 1998; Suryavanshi, 1999; Rodríguez *et al*., 2008) and to be able to detect performance problems.

The aim of this work is comparing two of the most extended irrigation systems (sprinkler and drip irrigation systems) in Castilla- La Mancha (Spain), by using performance indicators, related to management of irrigated land, applied to 7 WUAs (command area of 4800 ha).

MATERIAL AND METHODS

Water Users Associations The Benchmarking technique was applied during three irrigation seasons (2006-2008) in seven WUAs belonging to the provinces of Albacete (WUA 1, WUA 2, WUA 5, WUA 6, and WUA 7) and Cuenca (WUA 3 and WUA 4), in Castilla – La Mancha Region (Spain). Four of them have sprinkler irrigation system (WUA 1, WUA 2, WUA 5, and WUA 6) and drip irrigation system the remainder (WUA 3, WUA 4, and WUA 7). The source of water is groundwater for all of them (Table 1).

Table 1. Characteristics of Water Users Associations

Water User Association	1	2	3	4	5	6	7
Command area (ha)	863	491	170	267	764	550	1671

Wells (number)	4	5	1	1	6	5	1
Pumping station (number of pumps)	11	6	4	4	3 (6 sectors) 2 (1 sector)	10	-
Water distribution network management	Rotacional schedule	On Demand	On Demand	On Demand	Rotacional schedule	On Demand	On Demand
On – farm irrigation methods	Sprinkler irrigation	Sprinkler irrigation	Drip irrigation	Drip irrigation	Sprinkler irrigation	Sprinkler irrigation	Drip irrigation
Main crops	Maize, Barley, Alfalfa, Onion	Maize, Vineyard, Carrot,Barley	Vineyard, Olive tree	Vineyard, Olive tree,Almond tree	Maize,Onion Barley	Maize,Barley Onion,Vineyard	Vineyard,Olive tree,Almond tree

Data acquisition and information management to obtain indicators The indicators utilized can be grouped as: 1) descriptive indicators and 2) performance indicators. Descriptive indicators are useful in describing the general characteristics and the infrastructure of each WUA. These indicators are classified into 10 categories (Malano and Burton, 2001): location, climate, soil, institutional and socio-economic aspects, water source and availability, size, water allocation and distribution, infrastructure, and cropping. Descriptive indicators were completed with information supplied by the managers of each WUA. Other sources of information have been climatic series from agroclimatic and termopluviometric weather stations, whereas World Reference Base (WRB, 1999) and Soil Taxonomy (USDA-NCRS, 2006) classifications in order to determine edaphic characteristics.

Performance indicators are classified into five groups: system operation, financial, productive efficiency, environmental performance, and energy (Table 2). Most system operation and financial indicators, which were previously developed by several researchers (Alexander, 1999; Malano and Burton, 2001; Rodríguez *et al*., 2008), have been modified to be applied in all WUAs. Productive efficiency and environmental performance are the most new important groups of indicators, which include information on gross and net crop margins, and applications of nitrogen, phosphorous, and potassium fertilizers. In addition, the importance of the energy indicators is highlighted, mainly those related to theoretical absorbed power in WUAs, consumed active energy, and energy efficiency of the pumping system.

Most performance indicators were completed with information and documentation provided by managers and farmers of each WUAs. Besides this information, for calculating energy indicators, it was necessary to measure hydraulic, electric, and topographic data, by using specialized equipment.

The measured hydraulic data were the discharge of all the pumps (wells and pumping stations), by installing a portable ultrasound flow meter (to 2.5 % accuracy) in the pumping pipe, and the pumping head, by installing a pressure transducer (to 1 % accuracy), following the methodology proposed by Moreno et al. (2007a). Water table level was determined by using an electric contact meter.

The electrical parameters measured in the pumping stations were current, voltage, power factor, and absorbed power. These parameters were measured by using an electrical network analyzer (to 1.5% accuracy). With the hydraulic and the electrical data, the frequency distribution of discharges from the pumping stations was obtained for each of the irrigation season (Moreno et al., 2007a).

Regarding the topographic parameters, the elevation of all hydrants and all key points in the network (pumping station, valves, and so on) was measured using high precision GPS equipment (with an error of less than 1 cm).

INGES software is used to manage the information on indicators using Visual Basic (version 6.0) and Microsoft Access to calculate the indicators after introducing the data.

By using the Model for Energy Analysis of Pumping stations (MAEEB)(Moreno et al., 2007b), the energy efficiency in pumping stations is determined, which is useful to calculate the average energy efficiency of the pumping system (EEB).

Table 2. Performance indicators

.Group	Indicator	
System operation	Annual irrigation water supply per unit irrigated area (V_TSr, $m^3 ha^{-1}$)	Annual relative water supply (ARAA)
	Main system water delivery efficiency (ED, %)	Annual relative irrigation water supply (ARAR)
Financial	Total CMS cost per unit irrigated area (CMSSr, € ha^{-1})	General expenses per unit irrigated area (GGSr, € ha^{-1})
	Average revenue per unit irrigation delivery (RbVs, € m^{-3})	General expenses per unit irrigation delivery (GGVs, € m^{-3})
	Total CMS cost per unit irrigation delivery (CMSVs, € m^{-3})	Staffing cost per unit irrigated area (CPSr, € ha^{-1})
	Energy cost per unit irrigated area (CENSr, € ha^{-1})	Staffing cost per unit irrigation delivery (CPVs, € m^{-3})
	Energy cost per unit irrigation delivery (CENVs, € m^{-3})	
Productive efficiency	Output per unit irrigated area (VPSr, € ha^{-1})	Gross margin per unit water demanded by the crops (MBNb, € m^{-3})
	Output per unit irrigation delivery (VPVs, € m^{-3})	Net margin per unit irrigated area (MNSr, € ha^{-1})
	Output per unit water demanded by the crops (VPNb, € m^{-3})	Net margin per unit irrigation delivery (MNVs, € m^{-3})
	Gross margin per unit irrigated area (MBSr, € ha^{-1})	Net margin per unit water demanded by the crops (MNNb, € m^{-3})
	Gross margin per unit irrigation delivery (MBVs, € m^{-3})	

	Units of nitrogen per unit irrigated area (UFNSr, UFN ha^{-1})	Units of phosphorus per unit water demanded by the crops (UFP_2O_5Nb, UFP_2O_5 m^{-3})
	Units of nitrogen per unit irrigation delivery (UFNVs, UFN m^{-3})	Units of potasium per unit irrigated area (UFK_2OSr, UFK_2O ha^{-1})
Environmental performance	Units of nitrogen per unit water demanded by the crops (UFNNb, UFN m^{-3})	Units of potasium per unit irrigation delivery (UFK_2OVs, UFK_2O m^{-3})
	Units of phosphorus per unit irrigated area (UFP_2O_5Sr, UFP_2O_5 ha^{-1})	Units of potasium per unit water demanded by the crops (UFK_2ONb, UFK_2O m^{-3})
	Units of phosphorus per unit irrigation delivery (UFP_2O_5Vs, UFP_2O_5 m^{-3})	
	Measured absorbed power per unit irrigated area (NtSr, kW ha^{-1})	Hidraulic power per unit irrigation delivery (NhVs, kW m^{-3})
	Hidraulic power per unit irrigated area (NhSr, kW ha^{-1})	Consumed active energy per unit irrigation delivery (EacVs, kWh m^{-3})
Energy	Consumed active energy per unit irrigated area (EacSr, kWh ha^{-1})	Energy load index (ICE, m)
	Measured absorbed power per unit irrigation delivery (NtVs, kW m^{-3})	Average energy efficiency of the pumping system (EEB, %)

CMS: Total management, operation and maintenance cost

Statistical treatment Cluster Analysis (CA) is an ordination distribution-free technique to group sites with similar characteristics by considering an original group of variables (Peña, 2002). By means of this technique, groupings between WUAs with different irrigation systems are shown, in order to establish similarity between them.

Agglomerative Hierarchical CA is applied to group WUAs by using all performance indicators. CA is utilized for each kind of indicators (system operation, financial, productive efficiency, environmental performance, and energy). Two different similarity-dissimilarity measures are used: Euclidean distance and the correlation coefficient (Alhamed et al., 2002; Unal et al., 2003). In order to link clusters, single linkage is used, which is based on the shortest distance between objects.

The following expressions are shown to determine Euclidean (D_1) and correlation distance (D_c):

$$D_1 = \sqrt{\sum_{i=1}^{n} (X_{ij} - X_{ik})^2} \qquad (1)$$

X_{ij} is the value of the indicator i of the WUA j; X_{ik} is the value of the indicator i of the WUA k.

$$D_c = 1 - \left(\frac{\sigma_{ab}}{\sigma_a \cdot \sigma_b} \right) \qquad (2)$$

σ_{ab} is the covariance between WUAs a and b; σ_a is the standard deviation of the WUA a; σ_b is the standard deviation of the WUA b.

RESULTS

Analyses of the obtained indicators The performance indicator annual irrigation water supply per unit irrigated area (V_TSr, m^3 ha^{-1}) is a useful indicator to explain the main characteristics of the WUAs. The sprinkler irrigation system shows the highest value of V_TSr, close to 6000 m^3 ha^{-1} (Fig. 1), higher than in drip irrigation system, being approximately 1200 m^3 ha^{-1}. The values of V_TSr are related to crop distribution in each WUA, since the WUAs with sprinkler irrigation systems have crops with high water requirements (maize, onion, among others), different from crops with low water requirements (vineyard, olive tree, almond tree) of the WUAs with drip irrigation systems.

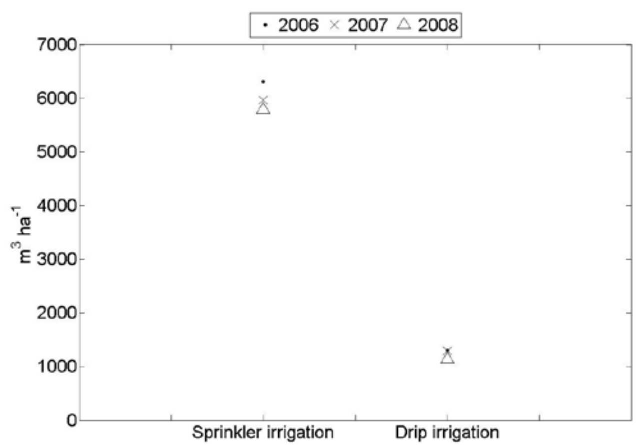

Figure 1. Annual irrigation water supply per unit irrigated area (V_TSr, m^3 ha^{-1})

The degree of fitting between crop water requirements and water irrigation applied is shown by means of annual relative irrigation water supply (ARAR) indicator. The most adequate value for ARAR, close to 1, is shown in sprinkler irrigation system, with an average value of 1.03. This indicator shows that the amount of irrigation water applied is much more reasonable for crops with high water requirements such as maize or onion, even more than other crops such as barley and wheat, which amount of irrigation water applied is lower than the actual crops water requirements. In the drip irrigation system, ARAR average value (1.16) shows an amount of irrigation water applied higher than crop requirements.

Regarding main system water delivery efficiency (ED, %) indicator, it reaches high values in sprinkler irrigation systems, with an average value close to 93 % (Fig. 2), which is slightly lower in drip irrigation system (80 %). The ED values in WUAs with drip irrigation systems can be lower than the expected due to the filters and pipes cleaning process, and not only due to water distribution system losses, and stored water evaporation.

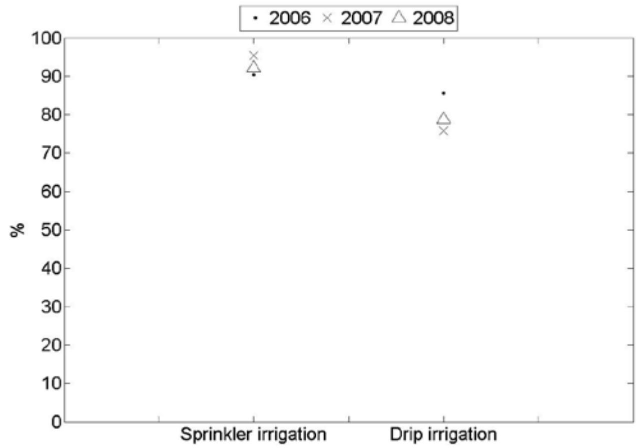

Figure 2. Main system water delivery efficiency (ED, %)

Considering the energy cost per unit irrigation delivery (CENVs, € m^{-3})(Fig. 3), the differences between sprinkler and drip irrigation systems are reduced. The average values of CENVs are very similar in both irrigation systems and comprised between 0.061 € m^{-3}, in sprinkler irrigation system, and 0.071 € m^{-3}, in drip irrigation system. The similarities between them can be explained because in all the WUAs analyzed, groundwater resources are the main source of water, and the pumping head of wells are also similar (122 m in WUAs with sprinkler irrigation system and 115 m in WUAs with drip irrigation system), which increase the CENVs value in both irrigation systems.

The importance of the energy costs in both on - farm irrigation methods is shown by means of the percentage that represents the energy cost in comparison with total management, operation and maintenance cost (CMS, €). This proportion is close to 70 % in WUAs with sprinkler irrigation system, and close to 45 % in WUAs with drip irrigation system.

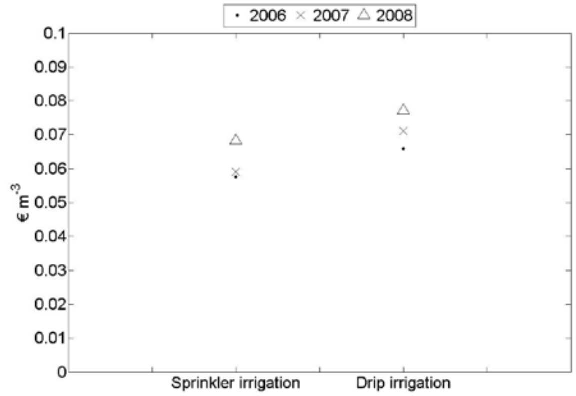

Figure 3. Energy cost per unit irrigation delivery (CENVs, € m^{-3})

Another important group of indicators are related to output (VPVs, € m^{-3}) and gross margin per unit irrigation delivery (MBVs, € m^{-3}). Regarding VPVs, in WUAs with sprinkler irrigation system, although the output per unit irrigated area is higher than in WUAs with drip irrigation system, the differences between both irrigation systems are reduced comparing VPVs indicator. In sprinkler irrigation system, VPVs reaches an average value close to 0.81 € m^{-3}, due to the presence of crops with high water requirements (maize, onion, carrot, potato, among others). On the other hand, in drip irrigation system, which have crops with low water requirements, VPVs indicator is higher (2.5 € m^{-3}).

In case of MBVs indicator, the differences between sprinkler irrigation system and drip irrigation system are not high, with values comprised between 0.36 € m^{-3} and 0.85 € m^{-3}, respectively. The highest differences between VPVs and MBVs in drip irrigation system could be due to high production costs of vineyard, almond tree, and olive tree, which are social crops with high demand of employees.

Regarding the indicators related to measured absorbed power (Nt) of wells and pumping stations, such as measured absorbed power per unit irrigated area (NtSr, kW ha^{-1}) indicator, there are slightly differences between WUAs with sprinkler irrigation systems and drip irrigation systems, with values comprised between 3.91 kW ha^{-1} and 2.79 kW ha^{-1}, respectively. In spite of this, those differences are not too high in both irrigation systems, because all WUAs analyzed utilize wells with similar characteristics to extract groundwater resources, due to the high distance to water table and high pumping head in all societies, increasing the NtSr values.

Another energy indicator to consider is the energy load index (ICE, m)(Fig. 4), which is similar between sprinkler irrigation system (166 m) and drip irrigation system (142 m). This fact can explain the highest energy costs in both irrigation systems. Although there are small differences between pumping head of wells in all WUAs analyzed, ICE value is slightly higher in WUAs with sprinkler irrigation systems than WUAs with drip irrigation system. It can be explained because in sprinkler irrigation system, the pumping head of the pumping station is higher (55 m) than in drip irrigation system (40 m).

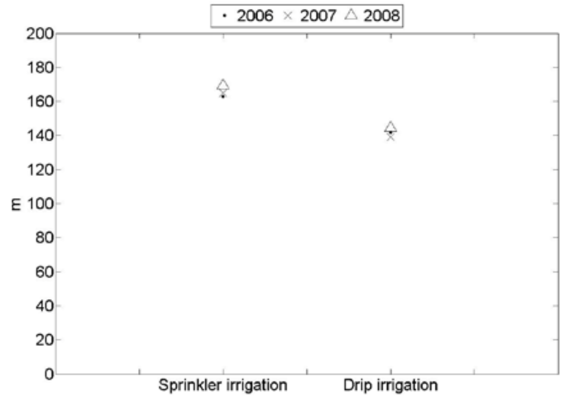

Figure 4. Energy load index (ICE, m).

Cluster Analysis Differences between WUAs with sprinkler and drip irrigation system are shown in Figure 5. Two clusters are obtained, the first cluster is formed by WUAs with sprinkler irrigation system (WUA 1, WUA 2, WUA 5, and WUA 6), and the second cluster is formed by WUAs with drip irrigation system (WUA 3, WUA 4, and WUA 7). The differences in the group of drip irrigation systems are higher than in the other group. This fact can be due to the higher impact of management changes in WUAs with drip irrigation systems than in those with sprinkler irrigation systems.

In the Cluster 1, which includes all the WUAs with sprinkler irrigation systems, the similarity between WUAs managed to work under a rotational scheduling, as WUAs 1 and 5, and between WUAs managed to work on demand, as WUAs 2 and 6, is shown (Fig. 5).

WUAs 1 and 5 have a similar cropping pattern, and the highest values of irrigation water delivered per unit of area, being between 6100 m^3 ha^{-1} and 6600 m^3 ha^{-1}. Energy cost per unit of area of both WUAs is lower than for the rest of WUAs with sprinkler irrigation systems. In WUA 1, a 35 % of volume irrigation supply is superficial water source and in WUA 5, the average pumping head of wells is the lowest comparing to the rest of WUAs, which can explain the lower energy requirements of both WUAs. Energy cost in WUAs 1 and 5 has less participation in the CMS cost than in WUAs 2 and 6 (61 % in WUA 1 and 66 % in WUA 5). The total annual value of agricultural production per unit of area and irrigation water has similar results in WUAs 1 and 5, since they have similar crops distribution. The measured absorbed power per unit of area and volume of irrigation water, together with the consumed energy explain WUAs 1 and 5 clustering. In addition, ICE is very similar for both WUAs.

WUAs 2 and 6 utilize less volume of irrigation water applied to the crops than the rest of the WUAs with sprinkler irrigation systems (approximately 5700 m^3 ha^{-1}). The total CMS cost per unit area is the highest in WUAs 2 and 6, mainly due to the high energy cost of both WUAs, which represent between a 71 % (WUA 6) and 78 % (WUA 2) of the CMS cost. The high energy cost in WUAs 2 and 6 can be due to the high distance to water table and high pumping head in WUAs 2 and 6. In addition, WUA 6 is an on demand irrigation network, which usually requires more energy to irrigate.

The cluster 2 groups all the WUAs with drip irrigation systems, where WUAs 3 and 4 show high similarity (Fig. 5). Both of them are on demand irrigation networks, with the major part of the area with vineyard crops. Irrigation management of WUAs 3 and 4 is very similar, with an average of volume water delivered close to 1500 m^3 ha^{-1}. The participation of the energy cost is approximately 45 % of the total management, operation, and maintenance cost (CMS, €). Regarding productive efficiency, crops production is also very similar, with similar crops prices and with an output per unit area close to 2400 € ha^{-1}. In addition, crops production costs are similar in WUAs 3 and 4, together with the gross margin per unit of area and irrigation water. Regarding energy indicators, WUAs 3 and 4 show similar characteristics, with an average depth to water table about 100 m, without differences relative to average pumping head.

WUA 7, the third WUA with drip irrigation systems, shows less similarity with WUAs 3 and 4 (Fig. 5). Although the three WUAs have mostly vineyard, WUA 7 has more almond and olive trees than WUAs 3 and 4. In WUA 7, the energy consumption is not too high, because this WUA does not need a pumping station. Crop management is different than in WUAs 3 and 4 with an average of volume water delivered lower than 950 m^3 ha^{-1}. In WUA 7, the higher experience of farmers about crop management in comparison to WUAs 3 and 4 can explain the lower values of crops production costs.

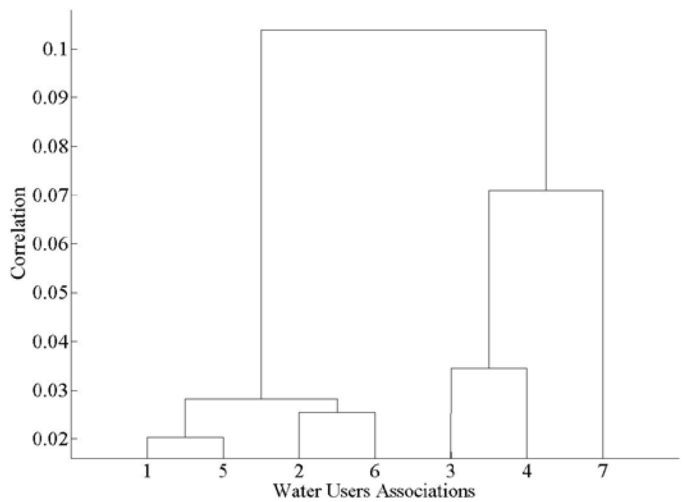

Figure. 5. Dendrogram for water users associations clustering.

CONCLUSION In drip irrigation system, although the volume of irrigation water supply is lower than in sprinkler irrigation system, it is important to control the main system water delivery efficiency, reducing irrigation water losses when filtering system is cleaned.

Regarding crops water management, in drip irrigation system, with a high presence of vineyard, olive tree, and almond tree, in most of the plots the irrigation water applied is slightly higher than crops water requirements. Therefore, it is necessary the use of different tools to help to improve crops management (mainly in vineyard), such as the irrigation advisory services.

Efficiency productive indicators related to total annual value and total annual gross margin of agricultural production per unit irrigated area and irrigation water delivered, show high differences between WUAs with drip irrigation system and with sprinkler irrigation system.

The importance of energy cost is high in both irrigation systems, since it represents, in sprinkler irrigation system, a 70 % of total management, operation and maintenance cost, and a 45 % in drip irrigation system.

When using groundwater resources, there are no high differences in the energy consumption between WUAs with drip irrigation systems and those with sprinkler irrigation systems, since most of the energy is utilized to pump the water from the aquifer.

In all WUAs, due to the use of groundwater resources, it is necessary to inspection periodically pumping stations and, mainly, wells, by using methodologies, such as Energy Audits, for reducing the consumed active energy and improving the efficiency of pumps.

Cluster Analysis applied to WUAs shows a notable difference between irrigable areas with sprinkler irrigation systems and with drip irrigable systems. The similarities between areas irrigated with sprinkler irrigation systems are higher than between WUAs with drip irrigation systems.

The application of Becnhmarking techniques, by using indicators, is a useful manner to characterize WUAs and to evaluate water and energy management. WUAs should apply this methodology, in order to improve their management and to make the work of users and managers of WUAs easier

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REFERENCES

Alexander, P. 1999. Benchmarking of Australian Water Providers. Hydro Environmental. Australian National Committee on Irrigation and Drainage, Melbourne, Australia.

Alhamed, A., Lakshmivarahan, S., Stensrund, D.J. 2002. Cluster analysis of multimodel ensemble data from SAMEX. Mon Wea. Rev. 130, 226-256.

Degirmenci, H., Büyükcangaz, H., Kuscu, H. 2003. Assessment of irrigation schemes with comparative indicators in the Southeastern Anatolia Project. Turk. J. Agric. For. 27: 293-303.

Dembele, Y., Quattara, S., Keïta, A. 2001. Application des indicateurs “Approvisionnement relatif en eau” et “productivité de l’eau” à l’analyse des performances des petits perimètres irrigués au Burkina Faso. Irrig. Drain. 50: 309-321.

Kloezen, W.H.; Garcés, C. 1998. Assessing Irrigation Performance with Comparative Indicators: The Case of Alto Rio Lerma Irrigation District, México. IWIMI Research Report, 22, International Irrigation Management Institute (IWMI), Colombo, Sri Lanka.

Malano, H., Burton, M. 2001. Guidelines for Benchmarking Performance in the Irrigation and Drainage Sector. International Programme for Technology and Research in Irrigation and Drainage (IPTRID), Rome, Italy.

Malano, H., Burton, M., Makin, I. 2004. Benchmarking performance in the irrigation and drainage sector: a tool for change. Irrig. Drain. 53, 119-133.

Molden, D., Sakthivadivel, R., Perry, C.J., Fraiture, C., Kloezen, V.H. 1998. Indicators for comparing performance of agricultural systems. Research Report 20. International Irrigation Management Institute (IWMI), Colombo, Sri Lanka.

Mondal, M. S., Saleh, A. F. 2003. Evaluation of some deep and shallow tubewell irrigated schemes in Bangladesh using performance indicators. Agric.Water Manag.58: 193 - 207.

Moreno, M.A., Carrión, P.A., Planells, P., Ortega, J.F., Tarjuelo, J.M. 2007a. Measurement and improvement of the energy efficiency at pumping stations. Biosyst. Eng. 98, 479-486.

Moreno, M.A., Pelayo, J., Córcoles, J.I., Planells, P., Carrión, P., Tarjuelo, J.M. 2007b. Model for analysis of energy efficiency at pumping stations (MAEEB). 10th Inter-Regional Conference on Water and Environment, October 17-20, New Delhi, India.

Ortega, J.F., de Juan, J.A., Tarjuelo, J.M., López, E. 2004. MOPECO: an economic optimisation model for irrigation water management. Irrig. Sci. 23, 61–75.

Peña, D. 2002. Estadística: Modelos y métodos 2. Modelos lineales y series temporales. 2ª ed. Alianza Editorial, S.A., Madrid, España.

Rodríguez, J.A., Camacho, E., López, R., Pérez, L. 2008. Benchmarking and multivariate data analysis techniques for improving the efficiency of irrigation districts: An application in Spain. Agric. Syst. 96, 250-259.

Sodal, S.V. 2004. Present practices and opportunities for performance improvement of irrigation schemes in Maharashtra State of India. Irrig. Drain. Eng. 53: 175-183.

Suryavanshi, A.R. 1999. Performance evaluation of irrigation system for rehabilitation: with case studies. ICID 17th Congress, September 11-19, Granada, Spain.

Unal, Y., Kindap, T., Karaca, M. 2003. Redefining the climate zones of Turkey using Cluster Analysis. Int. J. Climatol. 23, 1045-1055.

USDA-NCRS. 2006. Keys to Soil Taxonomy.10th ed., United States Department of Agriculture, Natural Resources Conservation Services, Washington D.C., WA, USA.

WRB. 1999. World Soil Resources Reports. World Reference Base for Soils Resources. International Society of Soil Science. International Soil Reference and Information Centre and FAO.