International Commission on Irrigation and Drainage

26th Euro-mediterranean Regional Conference and Workshops
« Innovate to improve Irrigation performances »

12-15 October 2015, Montpellier, France

WORKSHOP : IRRIGATION AND ENERGY

REDUCING THE ENERGY DEMAND IN IRRIGATION WATER SUPPLY SYSTEMS. EXPERIENCES FROM SOUTHERN EUROPE

González Perea[1]R.; Camacho[2]E.; Montesinos[3]P.;Fernández García[4]I.; Rodríguez Díaz[5], J.A.;

ABSTRACT

In recent years, many modernization processes have been undertaken in irrigation districts with a view to improving water use efficiency. In southern Spain, many irrigation districts have either been modernized or are currently being upgraded. However, as part of the modernization process some unexpected side effects have been observed. This paper analyzes the relative advantages and limitations of modernization based on field data collected in a typical Andalusian irrigation district. Although the amount of water diverted for irrigation to farms has been considerably reduced, consumptive use has increased. The costs for operation and system maintenance have dramatically risen (400%), as the energy for pumping water is much higher now compared to the gravity fed systems used previously. Then a regional analysis of the relationship between energy requirements and irrigation water applied in ten irrigation districts, in Southern Spain, has been carried out. Results show that 1000 kWh ha^{-1} is the energy required to apply an average depth of 2590 m^3 ha^{-1}. Finally, energy saving options are identified and discussed.

Keywords:energy use; performance indicators; pressurized irrigation networks; Spain.

[1]*Department of Agronomy.University of Córdoba.CampusRabanales, Edif.da Vinci, 14071. Córdoba.Spain. E-mail: g72goper@uco.es*
[2]*Department of Rural Engineering.University of Córdoba. Campus Rabanales, Edif. da Vinci, 14071. Córdoba. Spain. E-mail: ecamacho@uco.es*
[3]*Department of Agronomy.University of Córdoba. Campus Rabanales, Edif. da Vinci, 14071. Córdoba. Spain. E-mail: pmontesinos@uco.es*
[4]*Department of Agronomy.University of Córdoba.CampusRabanales, Edif.da Vinci, 14071. Córdoba.Spain. E-mail: g52fegai@uco.es*
[5]*Department of Agronomy.University of Córdoba. Campus Rabanales, Edif. da Vinci, 14071. Córdoba. Spain. E-mail: jarodriguez@uco.es*

1. Introduction

The improvement of agricultural water management to increase crop productivity, reduction of droughts impacts and the promotion of water conservation practices are the main challenges of current irrigated agriculture in Spain. Since 2002, the Spanish government has developed a National Irrigation Plan and an Emergency Plan for Modernization of Irrigation with the aim of saving 3000 Mm3 of water per year (MARM, 2002 and 2006). These involved an investment of some M€ 7400, affecting about 2 Mha of the 3.5 Mha of existing irrigation area (Lecina et al., 2010).

With a view of increasing the irrigation efficiency and to give farmers maximum flexibility, many water distribution networks have been designed to supply pressurized water and arranged on-demand. Thus, new pressurized networks have replaced some of the obsolete open-channel hydraulic infrastructure. This change increases the conveyance efficiency reducing water losses throughout the system. In addition, farmers get a much greater degree of flexibility. A good example is Bembézar M. D. (BMD) Irrigation District (Southern Spain), a typical irrigation district in the Guadalquivir river basin,that supplies water to 11,950 ha. After the modernization process, eleven pumping stations operate along the main channel to supply water to each sector. The network was designed to supply 1.2 L $s^{-1}ha^{-1}$ on-demand at a minimum operational pressure head at the hydrant level of 35 m of water.

However, Corominas (2009) reported than while water use has been reduced by 21% from 1950 to 2007 at national level, the energy demand was subsequently increased by 657%. As total energy costs have significantly risen in recent years, modernization is sometimes an additional problem for farmers because it has led to an increase in water costs (Rodríguez Díaz et al., 2009). Other additional costs that arise after the modernization process are the amortization costs of the infrastructure and installation of irrigation systems and the operating costs. The Spanish Ministry of Agriculture and Environment, in their study of cost-effectiveness analysis indicated an approximate annual cost of € 600 ha^{-1} each year to cover amortization and operation costs (MARM, 2009).

This work offers a broad perspective of the current situation of the energy demand for irrigation supported by real data from irrigation districts and shows different alternatives for reducing the energy dependence.

2. Water and energy use in Andalusian irrigation districts

2.1 Changes in Water and Energy use

To compare the pre and post modernization management, the indicators set proposed by the IPTRID (International Program for Technology and Research in Irrigation and Drainage) (Malano and Burton, 2001) and adapted to the Andalusian irrigation districts by Rodríguez-Díaz et al. (2008) were calculated in BMD irrigation district for eight irrigation seasons: six before modernization (from 1996 to 2002) and two after the upgrade (2008 and 2009). Then the indicators averages before and after the modernization process were then compared.

The total water diverted for irrigation in this district was reduced from 8000 m^3 ha^{-1} to 4700 m^3 ha^{-1} after modernization, so approximately 40% less was diverted from the reservoirs. The main reason for that could be the improvement in conveyance efficiency, with less water losses in distribution, and the increased irrigation efficiency of the irrigation system (surface shift to drip). In BMD, farmers shifted from a fix tariff per irrigated area to a binomial tariff where fix costs are paid per irrigated area and volumetric billing to cover energy costs (around € 0.027 m^{-3}). Due to the increased energy costs, the local farmers' practices have changed towards deficit irrigation. On the other hand, the cropping pattern has also changed after the modernization. In general, farmers tend to move to more profitable crops, trying to offset the higher costs of the new system with an increase in farm income. Other authors reported that these changes sometimes lead to an increment in consumptive use of water (Playán and Mateos, 2006; Perry et al., 2009).

For example, in BMD, both irrigation requirements (highly influenced by rainfall) and theoretical crop water requirements increased by around 20% after the upgrade. While the irrigation water supply exceeded the irrigation requirements by nearly 40% before modernization, now it represents only 70% of irrigation needs. The current deficit irrigation practices guarantee that the consumptive use of water is even smaller than before modernization. This means that in the previous situation much water was not used by the crops and therefore returned to the system and now, with deficit irrigation these return flows are significantly reduced. Taking into account the financial impact is clear that while farmers originally needed 2.6% of their income to cover water costs, in the current situation, this ratio has now increased up to 10%. The main reason for this increment is the high energy consumption required to pump and distribute water which forces the farmer to think about the profitability of irrigating their crops. Therefore, in BMD as in other many districts, energy has become an important cost that limits irrigation more than water availability.

2.2 Upscaling the energy problem in pressurized systems

Ten typical Andalusian (Southern Spain) irrigation districts were studied to visualize the efficiency of the use of water and energy simultaneously at a regional scale. For that, performance indicators were calculated for the 2006-07 irrigation season (Rodríguez- Díaz et al. 2011). Collectively, the selected irrigation districts cover a total irrigated area of more than 66,000 ha representing a wide variety of crops. All of them are arranged on-demand 24 h day^{-1} with pressurized water available to farmers. A detailed description of the water and energy performance indicators analysis is available at

Rodríguez-Díaz et al. (2011). The selected indicators and their averages, value ranges and standard deviations for different measures of energy and power consumption are shown in Table 1.

A clear relationship between energy required for pumping and irrigation efficiency was found (Table 2) where the annual energy consumption per unit of irrigation water and the RIS (relative irrigation supply (reference)) are shown. Although there are exceptions, it can be observed that in districts with smaller energy requirements, the RIS was bigger and when more energy was needed for pumping the water, less irrigation water was applied.

Table 1.Average, range and standard deviation of the selected indicators for ten irrigation districts.

Irrigation district	Average	Range	Std dev.
Annual irrigation water supply per unit irrigated area ($m^3 \cdot ha^{-1}$)	2589	5138-1435	1079
Pressure head (m)	89	168-47	40.4
Annual Energy consmption (MWh)	4647	9148-855	2797
Energy consumption per unit of irrigated area ($kWh \cdot ha^{-1}$)	1003	1901-455	418.1
Energy consumption per unit of irrigation water supplied ($kWh \cdot m^{-3}$)	0.41	0.89-0.15	0.2
Power per unit of irrigated area ($kW \cdot ha^{-1}$)	1.56	3.48-0.88	0.8
PEE (%)	58	85-31	16.1
Total MOM cost per unit volume supplied ($€ \cdot m^{-3}$)	0.10	0.18-0.04	0.04
Energy to total MOM costs ratio (%)	36.4	65.3-16.1	15.1

PEE: Pumping Energy Efficiency MOM: Management, Operation and Maintenance

Table 2. Irrigated areas, relative irrigation supply (RIS) and energy consumption per unit of irrigation water supplied for ten irrigation district.

Irrigation district	Irrigated area (ha)	RIS	Energy consumption per unit of irrigation water supplied (kWh/m^3)
F. Palmera	5611	0.41	0.73
Palos	3343	3.70	0.25
Las Coronas	450	0.96	0.34
El Villar	2726	0.24	0.89
Genil-Cabra	16100	0.85	0.33
M. D Bembezar	11262	0.85	0.15
P. Guadiana	4520	0.78	0.33
P. Bancos	1336	0.46	0.53
Los Dolores	4500	0.50	0.39
C. Noroeste	8383	0.51	0.17

3. Potential energy saving measures

In pressurized systems, energy is now becoming a major factor influencing cost as important as others such as water availability, rainfall or evapotranspiration. In this context, recent international research has highlighted the need to optimize both water and energy efficiency. In Spain, IDAE has developed a protocol where some of the most common energy saving measures for pressurized systems were identified (Rocamora et al., 2008). Some of the proposed actions by several authors are summarized below:

Irrigation network sectoring: usually the pressure head at the pumping station is set to supply pressurized water to the highest pressure-demanding hydrant while other hydrants receive an excess of pressure that must be removed by hydraulic valves. Network sectoring consists of grouping hydrants with similar energy requirements. Then the network is operated in turns and each sector is enabled a few hours every day only and the pressure head is set according to the worst hydrant (pressure demand) in the sector. Results of several authors showed that savings of more than 20% in energy could be achieved in the peak demand period for the current water demand levels, by operating the network in sectors and concentrating irrigation events per sector into 12 h rather than 24 h.

Critical points detection: critical pressure points are those with special energy requirements, usually caused by their distance from the pumping station and/or their elevation, which determine the minimum pressure head required at the pumping station. Thus, sometimes a few points are responsible for large fractions of the total pressure head at the pumping station. In these cases other strategies such as booster pumps or changes in pipes size, would lead to important energy savings. In Fuente Palmera irrigation district, Rodríguez-Díaz et al. (2009) showed that 15 critical points (from a total of 85 hydrants) were responsible for almost 15 m of the total pressure head.

Improvingthe energy efficiency of the pumping system: usually pumping stations are designed to provide water at the peak demand period. However, as this period takes only 2 or 3 months, and the rest of the year the demanded flows are much lower, and therefore the pump operation point is not the optimum to maximize their PEE (Pumping Energy Efficiency). By installing new smaller pumps, more appropriate for flows demanded during off-peak periods, and using variable speed pumps, it is possible to increase PEE significantly and therefore reduce energy consumption (Moreno et al., 2009).

Irrigation systems at farm level: theoretically more efficient irrigation systems and better irrigation scheduling lead to significant simultaneous energy and water savings. Better irrigation scheduling techniques enable the application of the right amount of water when needed, avoiding excess applications. With more efficient irrigation systems the water properly applied and therefore water losses are reduced. Thus, both measures contribute to reduce water diversion for irrigation and energy requirements for pumping. Also low-pressure irrigation application systems are widespread nowadays so many of them can work with less than 10 m pressure. However, it is important to remind that for most farmers' the concept of water efficiency is linked to maximizing their farms' economic productivity rather than saving water per se, excepting perhaps when their own allocated resources may be inadequate (Gonzálezet al., 2014).

Water supply using solar energy: In Southern Spain, the irrigation season is mainly concentrated between March to October. Simultaneously, the PV (Photovoltaic) systems have their peak energy production in these months. Then, solar radiation and evapotranspiration have parallel time distribution curves (monthly and daily), so the peak solar power generated coincide in time with the maximum irrigation water requirements. Consequently, PV systems have potential to be the most suitable renewable source for irrigation, even more when considering that the price of solar panels has dropped dramatically in recent years. A good example of solar irrigation is the Sun Water Project system developed by IWES (www.iwes.es), a spin-off of the University of Córdoba.

4. Conclusions

In recent years many irrigation districts are facing the challenge of how to improve the efficiency of their water distribution systems. In Spain the traditional way to achieve this has been the replacement of open channel distribution networks by on demand-pressurized networks. This effect has been evaluated in the particular case of Bembezar MD. Although results show a reduction of approximately 40%of water use, the energy requirements have dramatically risen. Thus the Total MOM (Management, Operation and Maintenance) costs have also dramatically increased after modernization, typically increasing fourfold. After modernization, energy represents 30% of total MOM costs.

The close relationship between irrigation and energy was evaluated in other ten irrigation districts where around 1000 kWh ha^{-1} were required to apply an average depth of 2589 m^3 ha^{-1}. Power requirements per unit of irrigated area were 1.56 kW ha^{-1}. As energy represents an important percentage of the total water costs (around 40%), in agriculture, nowadays water use and energy efficiency cannot be considered independently. There are realistic alternatives to increase energy use efficiency for irrigation. Some these energy saving options are presented in this work.

REFERENCES

CARRILLO-COBO M.T., RODRÍGUEZ-DÍAZ J.A., CAMACHO E., 2010. The role of energy audits in irrigated areas. The case of ‘Fuente Palmera’ irrigation district (Spain).Span J Agric Res 8(S2), S152-S161.

COROMINAS J., 2009. Agua y energía en el riego en la época de la sostenibilidad. Ingeniería del Agua 17(3), 219-233. [In Spanish].

GARCÍA-VILA M., LORITE I.J., SORIANO M.A., FERERES E. 2008. Management trends and responses to water scarcity in an irrigation scheme of Southern Spain.Agr Water Manage 95(4) 458-468.

GONZÁLEZ PEREA, R., CAMACHO POYATO, E., MONTESINOS, P., RODRÍGUEZ DÍAZ, J.A., 2014."Critical Points: Interactions between on-farm irrigation systems and water distribution network". IrrigationScience. 32:255–265

LECINA S., ISIDORO D., PLAYÁN E., ARAGÜES R., 2010. Irrigation modernization and water conservation in Spain: The case of Riegosdel Alto Aragón. Agr Water Manage 97, 1663-1675.

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.Rome. Italy.

MARM, 2002. Plan Nacional de Regadíos. Ministerio de Medio Ambiente, Medio Rural y Marino. Madrid. [In Spanish].

MARM, 2006. Plan de choque de modernización de regadíos. Ministerio de Medio Ambiente, Medio Rural y Marino. Madrid. [In Spanish].

MARM, 2009. Sistema de información para la caracterización de medidas para el análisis coste eficacia. Grupo de Análisis Económico del Ministerio de Medio Ambiente, Medio Rural y Marino. Madrid. [In Spanish].

MORENO M.A., PLANELLS P., CÓRCOLES J.L., TARJUELO J.M., CARRIÓN P.A., 2009.Development of a new methodology to obtain the characteristic pump curves that minimize the total costs at pumping stations.BiosystEng 102, 95-105.

PÉREZ URRESTARAZU L., RODRÍGUEZ-DÍAZ J.A, CAMACHO POYATO E., LÓPEZ LUQUE R., 2009. Quality of service in irrigation distribution networks.The case of Palos de la Frontera irrigation district (Spain). J Irrig Drain 135(6), 755-762.

PERRY C., STEDUTO P., ALLEN R.G., BURT C.M., 2009. Increasing productivity in irrigated agriculture: agronomic constraints and hydrological realities.Agr Water Manage 96, 1517-1524.

PLAYÁN E., MATEOS L., 2006. Modernization and optimization of irrigation systems to increase water productivity.Agr Water Manage 80, 100-116.

ROCAMORA M.C., ABADÍA R., RUIZ A., 2008. Ahorro y eficiencia energética en las comunidades de regantes. IDEA, Ministerio de Industria, Turismo y Comercio. Madrid. Spain. [In Spanish].

RODRÍGUEZ-DÍAZ J.A., CAMACHO-POYATO E., LÓPEZ-LUQUE R., PÉREZ-URRESTARAZU L., 2008. Benchmarking and multivariate data analysis techniques for improving the efficiency of irrigation districts: An application in Spain. AgrSyst 96, 250-259.

RODRÍGUEZ-DÍAZ J.A., LÓPEZ-LUQUE R., CARRILLO-COBO M.T., MONTESINOS P., CAMACHO-POYATO E., 2009. Exploring energy saving scenarios for on-demand pressurized irrigation networks.BiosystEng 104, 552-561.

RODRÍGUEZ-DÍAZ J.A, CAMACHO-POYATO E., BLANCO- PÉREZ M., 2011. Evaluation of water and energy use in pressurized irrigation networks in Southern Spain. J Irrig Drain Eng. doi:10.1061/(ASCE)IR.1943-4774. 0000338.