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Improvement of water and energy use in sprinkler irrigation under semi-arid conditions

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ABSTRACT

This study aims to assess the impact of sprinkler irrigation performance on the energy requirements of solid-set sprinkler irrigation systems. For this purpose, a methodology to evaluate the energy requirements for solid-set sprinkler systems was proposed. Experimental and simulated irrigation data were used to analyze the impact of water application efficiency on the energy required to distribute water on soil surface. Results show that the decrease in the water application efficiency from 81% to 69% due to deep percolation losses over the potato irrigation season greatly increases the water distribution energy (34.4%) with an increase in the energy cost (kWh per ton) of 22.4% as well as a reduction of 18% in the water use efficiency. Results indicate also that improvement of water application efficiency of irrigated tomato from 74.1% (day irrigation) to 86.8% (night irrigation) induced a reduction in the energy cost (kWh per ton) of 22.8% although the net seasonal irrigation depth for night time was larger than that for day time due to the decrease in wind drift and evaporation losses.

Keywords: Sprinkler irrigation; Energy; Application efficiency; Water distribution

1. Introduction

For the majority of the Mediterranean countries, scarcity of water resources, the ever-growing water demand and the increase in irrigation acreages make of rational water use a major concern. This objective may be achieved using pressurized irrigation systems (sprinkler and drip irrigation). Playán and Mateos (2006) indicated that improvement of the irrigation performance depends on the appropriate choice of the equipment according to the soil and climate characteristics, water availability and socio-economic conditions. According to Keller and Bliesner (1990), distribution uniformity, wind drift and evaporation losses (WDEL) as well as application efficiency are the prominent performance factors in the design and management of sprinkler irrigation systems. Clemmens and Dedrick (1994) indicated that when appropriately designed and managed, sprinkler irrigation systems can reach irrigation efficiency greater than 80%. Burt et al. (1997) reported that sprinkler irrigation performances are affected by climatic and technical factors such as wind speed, operating pressure, sprinkler characteristics and sprinkler spacing. Under sprinkler irrigation, the farmer is often faced to an economic dilemma. Indeed, under-irrigated areas results on a reduction of crop yield and inputs (fertilizers, phytosanitary products, etc.). Conversely, over-irrigation increases the cost of water pumping and can lead to yield losses by asphyxiation, leaching of nutrients, and may even lead to contamination of groundwater.

It is worthy to say that switching from surface to pressurized networks results in additional costs of investment, pumping and maintenance. Regarding the implication of sprinkler irrigation uniformity on water productivity, economic analysis results of Berman (2008) indicates that there are clear incentives for adopting more water-efficient systems despite the higher capital cost, because of the depressing effect of overwatering on crop yield. Under irrigation modernization process in Spain, Corominas (2010) reported that for the period 1970–2007, water consumption per hectare was reduced by 21%, while energy demand increased by 657%. Because of scarcity of water resources, Tunisian authorities have adopted a national program for water

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conservation and improvement of irrigation efficiency (Al Atiri, 2007). Furthermore, subsidies and incentives were granted to farmers willing to exchange their inefficient irrigation systems with modern ones. In Tunisia, sprinkler irrigation covers about 114,000 ha, representing 28.3% of the total irrigated area (DG/GREE, 2017). Notwithstanding the changing from surface to pressurized systems, a saving of 20% on the energy consumption can be achieved (ANME, 2011). This work is devoted (i) to evaluate the energy requirements for solid set sprinkler systems and (ii) to investigate the effect of irrigation performance on energy consumption of the on-farm sprinkler irrigation systems.

2. Materials and methods

2.1. Energy evaluation

The energy E (kWh) required to operate solid set sprinkler systems was evaluated based on the methodology developed by Amir et al. (1986) for linear-move irrigation machines. Fig. 1 illustrates the functional components of the irrigation infrastructure used to characterize the energy requirements for solid set sprinkler systems.

According to Fig. 1, the energy required for operating the solid set system can be split into two components: (i) the energy required to supply water from the source to the farm hydrant E_1 (kWh) and (ii) the energy required to distribute water to the irrigated area E_2 (kWh).

E_1 and E_2 may be written as following:

$$E_1 = \frac{\rho_w g V_d H_m}{36 \eta E_t} \quad (1)$$

$$E_2 = \frac{\rho_w g V_c H_d}{36 E_a} \quad (2)$$

where ρ_w is the specific weight of water (kg/dm^3), g is the acceleration of gravity (m/s^2), V_d is the volume of water to be applied to the irrigated area (m^3), V_c is the volume of water available to the crop (m^3), E_t is the water supply efficiency (%), E_a is the application efficiency (%), η is the pumping efficiency (dimensionless), H_m is the pressure head (m) required to deliver water from the source to the hydrant and H_d is the pressure head (m) required to distribute water on the soil surface.

Considering that application efficiency is:

$$E_a = 100 \left(\frac{V_c}{V_d} \right) \quad (3)$$

The total required energy is, therefore, calculated as the sum of E_1 and E_2 ($E = E_1 + E_2$):

$$E = \frac{\rho_w g V_c}{36} \left(\frac{100 H_m}{\eta E_a E_t} + \frac{H_d}{E_a} \right) \quad (4)$$

2.2. Application case studies

The above-mentioned energy calculation approach was applied to analyze the effect of irrigation performance on the energy E_2 (Eq. (2) required to distribute water at the soil surface. The first component E_1 is rather dependent on the water transport infrastructure.

For this purpose, experimental data on sprinkler irrigation performances (Yacoubi et al., 2010a, Yacoubi et al., 2010b) were used to analyze the impact of the on-farm application efficiency on the water distribution energy. Experimental associated field trials (Fig. 1) were performed in the irrigation perimeter of the lower valley of the Medjerda in northeast Tunisia.

Tables 1 and 2 summarize the values of the different parameters used to assess the energy required to distribute water on potato and tomato irrigated field, respectively.

T_0 is a control irrigation treatment corresponding to a management allowable deficit of 50% of the soil available water-holding capacity. In the second treatment T_1, the applied water depth is 30% greater than that applied with T_0 in order to minimize the under irrigated in the case of T_0.

3. Results and discussion

3.1. Case of the potato crop

3.1.1. Effect of the application efficiency on the water distributed energy

Table 3 shows that reduction in the application efficiency from 81% to 69% induces a substantial increase (34.4 %) in the energy required to distribute water on the soil surface.

3.1.2. Distribution energy cost

Table 4 summarizes the values of distribution energy costs expressed in Tunisian dinar per hectare and in kWh per ton of potato (one Tunisian dinar ≈ 0.36 USD). It should be highlighted that energy costs used in this work are those applied by the National Company of Electricity and Gas for day and night irrigation times.

Table 4 shows that the cost of energy distribution depends on the volume of water distributed on the field. Results

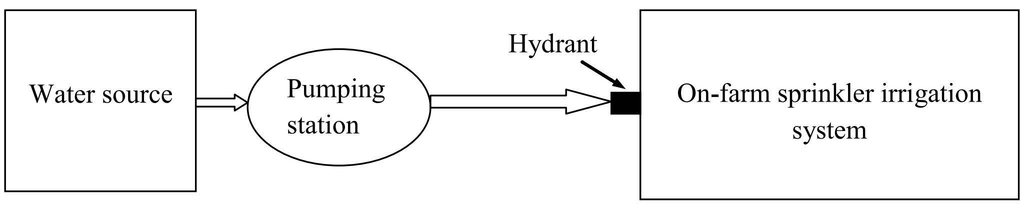

Fig. 1. Schematic representation of the irrigation infrastructures for energy requirement evaluation.

Table 1
Experimental data of sprinkler irrigated potato crop

	Treatment T_0	Treatment T_1
V_d (m³/ha)	3,200	4,300
E_a (%)	81	69
H_d (m)	36	36

Table 2
Experimental data of sprinkler irrigated tomato crop

	Day time	Night time
V_c (m³/ha)	5,490	6,417
E_a (%)	74.1	86.6
WDEL (%)	24	7
H_d (m)	35	35

Table 3
Effect of the application efficiency on the energy distribution

Treatment	V_d (m³/ha)	E_a (%)	E_2 (kWh/ha)
T_0	3,200	81	314
T_1	4,300	69	422

indicate also that reduction in application efficiency generates a relative increase of 22.4% in the energy cost expressed in kWh per ton as well as a relative decrease of 18% in the water use efficiency.

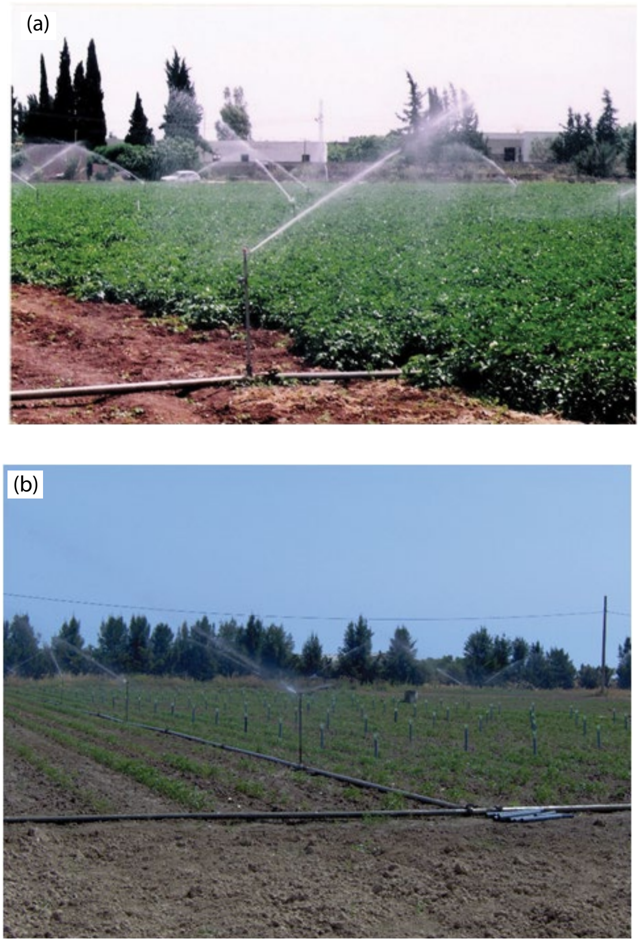

Fig. 2. Experimental sprinkler solid set systems: (a) potato crop, (b) tomato crop.

3.2. Case of the tomato crop

3.2.1. Distribution energy cost

For the tomato crop case, values of distribution energy costs are presented in Table 5.

Results show that irrigation time has a significant impact on distribution energy costs. Indeed, for night time, the energy cost (TND per hectare) was reduced by 22.8% although the net seasonal applied water was larger than that for day time. This reduction is due to the decrease in energy cost by night time. Also, results indicate that adoption of night irrigation reduces the energy cost expressed in kWh/T by 16.4% compared with day irrigation time.

Table 4
Energetic costs of the water distribution (case of the potato crop)

Treatment	Yield (T/ha)	Distribution energy cost (TND/ha)	Energetic cost (kWh/T)	Water use efficiency (Kg/m³)
T_0	46.2	40.1	6.8	14.4
T_1	50.7	53.9	8.3	11.8

Table 5
Energetic costs of the water distribution (case of the tomato)

Irrigation time	Relative yield loss (%)	Distribution energy cost (TND/ha)	Energetic cost (kWh/T)
Day	11	90.2	14.4
Night	3	69.6	12.0

4. Conclusion

A methodology to characterize and evaluate irrigation energy requirement for solid set sprinkler systems was presented in this work. Experimental data were used to analyze the impact of sprinkler irrigation performances on water distribution energy at the farm scale. Results obtained in this work indicated that energy and water saving can be achieved by improving irrigation efficiency and adopting proper irrigation management strategies. Under the arid and semi-arid local conditions, further investigations on the technical and socio-economic implications of irrigation modernization need to be assessed at a larger scale (irrigation district) in order to improve water and energy efficiency.

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