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Technical and economic study of irrigation scheduling devices on corn water productivity in a semi-arid region

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Abstract. It is essential to consider water allocation control and on-farm irrigation scheduling to increase water productivity in agriculture. There are several devices used for irrigation scheduling, however the best device with the most priority is not identified yet. In the present study, the effect of using several irrigation scheduling devices on increasing water productivity in a corn field was investigated. The devices were classified technically and economically using analytic hierarchy process. The experimental farm was located in a semi-arid region in Iran, which was managed by a farmer and irrigated with drip irrigation system. Six techniques for irrigation scheduling were studied including Penman-Monteith model (T2), infrared thermometer (T3), soil moisture meter (T4), tensiometer (T5), and gypsum block (T6). The irrigation scheduling treatments were compared with the conventional treatment adopted by the farmer (T1). Economic analysis was performed. The ease of use of the devices was also evaluated. Results showed for the irrigation scheduling treatments of T3 to T6, applied irrigation water was reduced by 11 to 26% compared to T1. The corn yield in irrigation scheduling treatments was not reduced significantly compared to T1. As a result, water productivity increased by 35% from 2.0 to 2.7 kg/m^3. The best irrigation scheduling device in terms of water productivity was gypsum block. In regard to affordability and ease of use by farmers, the Penman-Monteith model had more priority. Considering all assessment criteria, tensiometer (T5) was given the first priority. The infrared thermometer (T3) and Penman-Monteith model (T2) were identified as the next priorities.

Keywords: tensiometer, gypsum block, drip irrigation, canopy temperature.

INTRODUCTION

Unsustainable use of water resources has become a global problem. This problem is especially evident in the Middle East and North Africa. Over the last few years, digging deep wells has led to a sharp increase in groundwater abstraction. One of the effective solutions for reducing applied irrigation water has been the use of modern irrigation systems such as sprinkler or drip irrigation. Singh et al. (2016) stated that the need for food products will double by the next 50 years while 85% of the world's available water will be used for agriculture. Research in water-deficient areas of the world has shown that irrigation scheduling can save up to 35% in water and energy consumption. Forecasts suggest that all groundwater may be depleted within the next 50 years. Therefore, more attention needs to be paid to irrigation scheduling. It should be possible to answer the question of what changes occur in applied irrigation water by converting traditional irrigation methods to modern methods? The results show that in very limited cases the exact effect of modern irrigation systems has been documented. These studies generally show that the development of these technologies either has no effect on water consumption or has increased applied irrigation water. Also, the water productivity has remained more or less constant. Therefore, establishing a balance between sustainable water supply and consumption needs the physical control of water resources. Therefore, reducing allocations is also necessary (Perry and Steduto, 2017). Farmers should have appropriate devices to manage irrigation in farms.

Iran is located in a semi-arid region with an annual rainfall of 250 mm. Most of the water needed for agriculture comes from groundwater resources. In the Fars province, more than 70% of agricultural water is provided from groundwater resources. Improper use of water has led to the gradual depletion of these valuable resources. If this trend continues, it will lead to various economic and social problems such as the migration of farmers to large cities. In recent decades, the Iranian government has developed modern irrigation systems over the country. Due to the low price of agricultural water in Iran, farmers have been not interested in saving applied irrigation water. Therefore, in recent years, the government has begun to build and install smart water delivery meters. When the government begin to reduce the allocated water, it is more necessary to have a suitable tool to assess the time and volume of irrigated water that is called "irrigation scheduling". Irrigation scheduling requires special devices such as a variety of soil moisture meters, tensiometers, and models for measuring plant evapotranspiration.

Iranian farmers manage irrigation according to their experience, not using irrigation scheduling devices. The type of plant also affects the amount of applied water. For example, corn is relatively sensitive to water stress, especially from flowering to grain filling stage. Farmers usually over-irrigate cornfields. Corn water productivity in different countries averages between 1.1 to 2.7 kg/m^3 and the global average is reported to be 1.8 kg/m^3 (Zwart and Bastiaanssen, 2004).

In the Fars province of Iran, the amount of applied irrigation water in cornfields with conventional irrigation management method ranges between 6700 to 28400 m^3/ha with an average of 13300 m^3/ha. Yields vary between 2800 to 15000 kg/ha with an average was 8300 kg/ha. Hence, water productivity ranges between 0.3 and 1.8 kg/m^3, with an average of 0.7 kg/m^3 (Shahrokhnia, 2015).

The application of new irrigation scheduling technologies in Iran is only limited to a few research centers. In Cyprus, low-priced tensiometers produced in the country made this device very popular among farmers. Unfortunately, due to the poor product quality, all efforts were in vain and farmers lost their desire to use it. In Jordan, the use of tensiometers allowed water-saving of 30% of applied irrigation water, and farmers were satisfied. However, farmers in Turkey were unsatisfied with the application of tensiometers due to the low quality of these devices (FAO, 2002).

Pitts and Zuzueta (2007) introduced the different devices for irrigation scheduling. Four irrigation scheduling methods (tensiometer, water balance, plant canopy temperature, and a plant model) were assessed. Results showed that all four methods can be used successfully for corn irrigation scheduling. Using irrigation scheduling methods can allow saving roughly 30% of applied irrigation water (Steele et al., 2000). Irmak et al. (2000) measured canopy temperature and water stress index for irrigation scheduling of corn. The achieved results showed that for the crop water stress index values greater than 0.22, 50% of the plant available water is consumed and the plant experiences water stress. The crop water stress index was also suggested as an appropriate indicator for irrigation scheduling. Ghinassi et al. (2003) mentioned that tensiometers decreased 30% of applied irrigation water and suggested the device as a helpful tool for corn irrigation scheduling. Tensiometers are inexpensive and simple devices to be used by farmers but need periodic maintenances. Bauder and Waskom (2003) used gypsum block for irrigation scheduling of cornfields in the fine soils of Colorado, USA, and found it as an accurate tool for irrigation scheduling. In another study, tensiometers were used in cornfields under a furrow irrigation system. Results showed that applied irrigation water decreased by 25% (Mathew and Senthilvel, 2004). Cremona et al. (2004) evaluated two methods of farm irrigation scheduling, one based on measuring plant stress index (canopy temperature) and the other based on measuring soil moisture. They concluded that by measuring canopy temperature, the water productivity increases by 25%. Since canopy temperature shows the start time of irrigation, it can be used in combination with other methods to determine the end time of irrigation. Erdem et al. (2005, 2006) performed irrigation scheduling based on different levels of water stress index for watermelon and beans using an infrared thermometer. Results showed that this method was appropriate for irrigation management. Chawla and Bundela (2007) examined the advantages and disadvantages of tensiometers and gypsum blocks. They stated that these two devices may not be acknowledged by farmers for some reason. The limited range of measuring soil matric suction, inability to determine the amount of irrigation water and the duration of balancing with soil moisture, were the main reasons.

In a study in South Florida, irrigation scheduling was performed using tensiometers, based on estimation of evapotranspiration, and conventional irrigation. The amount of water used in the first two methods was equal to 31 to 36% of conventional irrigation. Plant growth and water productivity in the first two methods were better than conventional irrigation. Finally, irrigation scheduling based on tensiometer and evapotranspiration were selected as appropriate scheduling methods for irrigation (Migliaccio et al., 2010). Incrocci et al. (2014) stated that in Italy, irrigation scheduling of different plants was performed using tensiometer, soil moisture meters and estimation of evapotranspiration. Results showed that applied irrigation water decreased by 21 to 40% compared to the conventional irrigation method. Applied fertilizer also decreased by 39 to 74%. No significant decrease was observed in plant growth and crop quality (Incrocci et al., 2014). Watermelon yield increased by 30% with the use of a soil moisture meter for irrigation scheduling. This study was conducted in the sandy soils of South Carolina (Miller et al., 2014). Soulis et al. (2015) and Soulis and Elmaloglou (2018) emphasized the importance of accuracy, calibration and placement of soil moisture sensors in drip irrigation scheduling. They also stated that irrigation scheduling using soil moisture sensors plays an important role in saving water. Perea et al. (2017) scheduled strawberry irrigation in Spain using software that was installed on Android phones and used meteorological, plant and hydraulic information. The rate of water-saving was from 11 to 33%. Tensiometers were used to manage the subsurface irrigation of strawberries. Results showed that water productivity can be increased from 8 to 44% (Cormier et al., 2020). In a study in the USA, irrigation scheduling for cornfields was performed and compared using sensors that determine soil water suction and soil water balance method. Results showed that they were suitable sensors and had economically similar results to the soil water balance method (Da Cunha Leme Filho et al., 2020). Soybean irrigation was also scheduled by installing soil water suction sensors in Stoneville, USA. Results showed that irrigation scheduling did not reduce crop yield and water productivity, but increased the economic efficiency (Wood et al., 2020). Bahadur and Singh (2021) used tensiometers to schedule tomato irrigation. Results showed that the best matric suction for starting irrigation was 40 kPa with polythene block mulch.

Previous research has shown that due to water scarcity for agriculture, controlling water allocation and using different irrigation scheduling methods is necessary to increase water productivity. Irrigation scheduling requires devices that vary in accuracy, cost, and efficiency. In addition, the use of devices that do not have sophisticated technology should be recommended for illiterate farmers. Therefore, in this study, the effect of using several irrigation scheduling devices in a cornfield in a semi-arid region was investigated in terms of applied irrigation water, costs and ease of use.

MATERIAL AND METHODS

This research was conducted in a cornfield in Fasa plain in the Fars province of Iran (Figure 1). This region is located in the south of Iran and has a semi-hot and dry climate. Fasa is a fertile agricultural plain. It is cultivated with wheat in the winter and corn, tomato, cucumber, and other crops in the summer. The soil tex-

Fig. 1. Location of the study area.

ture of this area is medium to heavy (loam to clay loam) and the weather is relatively warm in summer. Average air temperature, air humidity, annual reference evaporation and annual rainfall in the region are 19.3 °C, 40%, 2756 mm and 295 mm, respectively. In recent years, the surface irrigation systems in many farms have been changed to the drip irrigation system. Despite the use of drip irrigation systems, proper management is not applied to irrigation yet. Regarding the high amount of applied irrigation water and low water productivity in cornfields in this region, it is essential to employ modern irrigation systems and implement proper water management practices.

This study was carried out in a local cornfield. Irrigation scheduling was performed using different devices. The soil texture was Silty Clay Loam (30% clay, 52% silt and 18% sand). The bulk density of the soil was 1.28 g/cm^3. The volumetric soil moisture contents at soil field capacity and permanent wilting point were 32 and 15%, respectively (measured using the pressure chamber method). Corn seeds were planted by the farmer on lines 75 cm apart. The length of planting lines was 95 meters and a strip drip irrigation pipe was placed on each line. Irrigation water was provided from the existing well in the field with no restriction on the time and amount of irrigation. The pH of soil saturated extract was 7.3 and the electrical conductivity of the irrigation water was 0.483 dS/m. To evaluate the technical, economic and ease of use of irrigation scheduling methods, 5 devices were considered as treatments of the experiment. The devices included tensiometers, gypsum blocks, an infrared thermometer, soil moisture measuring sensors and the Penman-Monteith evapotranspiration estimation model. Conventional irrigation scheduling, performed by the farmer, was also considered in the experiment as the control treatment. The experiment was performed as a randomized complete block design with 6 treatments and 3 replications:

T1 conventional irrigation managed by the farmer. The irrigation interval was approximately 5 days. No technical recommendations were given to the farmer. The amount of applied irrigation water by the farmer was measured using calibrated propeller flow meters with an accuracy of 1 l.

T2 Amount of evapotranspiration estimated by Penman-Monteith model. The irrigation frequency was 2 days.

T3 Irrigation scheduled using an infrared thermometer and the plant canopy temperature. The type of infrared thermometer used was Summit (model SIR100B) with an accuracy of 0.1 ° C.

T4 Irrigation scheduling based on soil volumetric moisture content. The irrigation scheduling was performed using a 5-cm soil moisture sensor (ECH2O, Decagon, USA). The accuracy of the device was approximately 0.1%. The critical soil moisture limit for starting irrigation was 23%. This value was calculated using the soil available water for the crop and management allowable depletion (MAD=50%).

T5 Irrigation scheduling based on soil water suction. This suction was measured by a tensiometer (Soil Moisture Co., USA) characterized by accuracy of 1 cm.

T6 Irrigation scheduling based on measurements of soil electrical resistance using a gypsum block device (Eijkelkamp). The critical limit for starting irrigation was 74 according to the device catalogue.

Each plot of the experiment consisted of four implantation lines connected to a calibrated water meter. The volume of irrigation water was measured and controlled with an accuracy of 0.1 l. In T4 to T6, device sensors (one sensor in each plot) were installed between two middle rows of each replication, about 30 centimeter from the closest emitter. The depth of sensors placement was 30 cm according to the density of plant root. Tensiometers, gypsum blocks, soil moisture sensors and canopy temperature were read every day. When the soil moisture reached the critical level (depletion of 50% of available soil moisture), the irrigation was started. Due to the limited range of measuring suction in tensiometers (80 c.bar), the management allowable depletion (MAD) was considered equal to 30% for starting irrigation in T5. The volume of irrigation water was the amount of water required to reach the soil water content corresponding to the field capacity. The volume of irrigation water per unit surface was 27 mm in T3, T4 and T6, and 16 mm in (T5). In T3, the lower and upper stress baselines, used to evaluate the crop water stress index, were adopted from the study of Irmak et al., (2000). The required meteorological data were also obtained from the automatic synoptic meteorological station of Fasa. The station was established in 1974 and it is located at 53°41’ E and 28°58’ N and 1288 m.a.s.l. For T5, characteristics of the soil moisture tension curve were used to convert soil suction data to soil moisture. This curve was obtained from a pressure chamber device in the laboratory. The critical soil suction limit for starting irrigation was 69 cm. The study was performed for two years. In all the six treatments, fertilizing and weeding were similar to T1 and was performed by the farmer. At the end of the growing season, the amount of crop grain yield and cumulative applied irrigation water were measured in the plots. The mean values were statistically compared using Duncan’s test. The rate of applied irrigation water reduction for T2 to T6 (compared to T1) was measured.

Table 1. Saaty Spectrum table.

Interpretation	Nonsignificant	Moderately important	Very important	Very strongly important	Extremely important
Equivalent quantity	1	3	5	7	9

Water productivity was obtained by dividing the grain yield by the amount of applied water and evaluated.

Economic evaluation

Irrigation scheduling devices are different in terms of technical and economic aspects. Farmers consider different criteria when they want to decide on something. Scientifically, multi-criteria decision-making models are recommended for such issues. These models are used to select the most appropriate choice among the several available based on quantitative and qualitative indicators. The characteristics, application and results of different irrigation scheduling devices may be technically and economically different. Therefore, selecting the best device is a multi-criteria decision that justifies the use of multi-criteria decision-making models. Multi-criteria decision-making models include a wide range of methods. Analytic Hierarchy Process (AHP) method for decision making is based on qualitative indicators and it is a suitable and common tool. This method allows users to consider quantitative and qualitative indicators in their evaluations for decision making. The method is based on a pairwise comparison of criteria and options and uses a tree hierarchy structure in decision making (Benitez et al. 2011; Brunelli et al., 2013). In the AHP, two options are compared according to the desired criteria. Using a specific spectrum, the qualitative assessment of the superiority of one option over another becomes quantitative. In this study, irrigation scheduling devices were considered as an option and the desired criteria by farmers were considered as a comparison criterion. The following steps were performed to determine the weight of the options and criteria.

1 - First, the superiority of the options based on each criterion is examined in pairs. This information is collected qualitatively from farmers and experts and was quantified using the spectrum in Table 1, which is known as the Saaty spectrum (Saaty, 1987).

Intermediate values are converted to quantitative equivalents as needed using the numbers 2, 4, 6, and 8, respectively.

2 - In the next step, the matrix of options is formed. The general shape of this matrix is:

$$\mathbf{A}=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1j} \\ a_{21} & a_{22} & \cdots & a_{2j} \\ \vdots & \vdots & \vdots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{ij} \end{bmatrix} \tag{1}$$

The method of completing matrix A is the following: considering options a_{11} and a_{12}, if option a_{12} is more important at farmer's point of view, a higher number from table 1 is given to cell a_{12}. In the same way, all the cells are completed by comparing the options.

3 - After completing the matrix cells, the matrix is normalized. For this purpose, the number in each cell is divided by the sum of the numbers in each column. Thus, the matrix R is obtained. Each cell of the matrix R is called r_{ij}, which is calculated as follows.

$$\mathbf{R}=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1j} \\ r_{21} & r_{22} & \cdots & r_{2j} \\ \vdots & \vdots & \vdots & \vdots \\ r_{i1} & r_{i2} & \cdots & r_{ij} \end{bmatrix} \tag{2}$$

$$\mathbf{r}_{ij}=\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{3}$$

4 - In the next step, the weight of each option and criteria are calculated. For this purpose, the cells of each row from matrix R are divided by the sum of the columns. Thus, the coefficient of importance (W_i) is determined as follows:

$$\mathbf{W}_i=\frac{\sum_{j=1}^{n} r_{ij}}{n} \tag{4}$$

Before using W_i, it is required to ensure the answers provided for pairwise comparisons are consistent. For this purpose, it is necessary to calculate the consistency rate (CR). If the CR is 0.1, the comparisons have the necessary compatibility; otherwise, the pairwise comparisons should be revised until the desired compatibility rate is reached. To calculate CR, the weighted sum vector (WSV) and consistency vector (CV) are calculated, respectively.

$$\mathbf{WSV = A.W} \tag{5}$$

$$\mathbf{CV}= \frac{WSV}{W} = \frac{A.W}{W} \tag{6}$$

The consistency index (CI) in this case is equal to:

$$\mathbf{CI}= \frac{\lambda_{\max} - n}{n-1} \tag{7}$$

$$\lambda_{\max} = \frac{(CV)_i}{n} \tag{8}$$

where $\lambda_{\max}$ is the largest eigenvalue of a'_{ij}, the perturbed value of a_{ij}. Using random numbers, a random consistency index (RI) is extracted for each matrix. After determining the random consistency index, the initial pairwise matrix is determined using the consistency ratio (CR):

$$CR = \frac{CI}{RI} \tag{9}$$

In this study, the opinions of experts and farmers were used to select the criteria, according to the factors affecting the acceptance of irrigation methods. For this purpose, 50 farmers were invited to a training class. After explaining the issue of irrigation scheduling to farmers, the most important factors that they considered in selecting irrigation scheduling tools were determined. Calculations related to pairwise comparison of options and determination of CR was performed using Expert Choice software. In addition to using the pairwise comparison method to prioritize the options, different experimental treatments were also compared economically. To compare the affordability of the choices, the following prices were considered. The price of devices, the maintenance costs, the replacement price, the time of irrigation, the number of workers used and applied irrigation water in each treatment were noted. Considering average prices and costs in the area, the difference between the costs of each treatment was calculated. To compare the affordability of the devices, the partial budgeting method was used. For this purpose, the control treatment under the farmer management was selected as the main treatment and other treatments were compared with that. The calculation method was as follows:

$$B = \Delta\pi_i - \Delta C_i \tag{10}$$

where in:

$\Delta\pi_i$ = The benefits of treatment i, compared to the farmer managed treatment

ΔC_i = The difference between the cost of treatment i, compared to the farmer managed treatment

Finally, the treatment with the highest value of B was selected as the best treatment. In the studied treatments, other costs were the same, except for irrigation and device costs. Therefore, to calculate the gross benefits of each treatment, only the sum of non-common costs of treatment was deducted from the gross income.

RESULTS AND DISCUSSION

Table 2 shows the results of irrigation scheduling treatments in the two years period of experiments. Results show that the highest and lowest applied irrigation water is related to Penman-Monteith (T2) and tensiometers (T5) with 7036 and 4763 m^3/ha. The difference of applied irrigation water between T3 and T4 was not statistically significant ($p<0.05$). The amount of water used in conventional irrigation management (T1) was 6404 m^3/ha. Therefore, the maximum amount of irrigation water saving was 26% (T5). In T2, the applied irrigation water resulted higher than T1 and no water-saving was observed. Therefore, in terms of saving applied irrigation water, priority was given to the treatment managed with the tensiometer (T5) followed by the one managed by canopy temperature measurements (T3), soil moisture meter (T4) and gypsum block (T6). The tensiometer treatment had the lowest applied irrigation water and the lowest crop yield (12387 kg/ha). The yield in T1 (12495 kg/ha) was not statistically different ($p<0.05$) from that obtained in treatment T5. The Penman-Monteith approach (T2) had the highest irrigation water, and the highest yield (16503 kg/ha). In general, with increasing the irrigation water, the yield was also increased. Therefore, in terms of water saving, the priority is represented by T5 followed by T3, T4 and T6, respectively. According to Table 2, water productivity in all irrigation scheduling treatments was significantly greater than T1 (1.96 kg/m^3). Although T6 had the highest water productivity (2.72 kg/m^3), its difference with T3 and T4 was not statistically significant. The difference between the water productivity of T2 and T6 was significant.

Table 3 shows the average productivity components of all the treatments measured within the two years of the experiment. Also, the averages for conventional surface irrigation systems in the area is presented. The average of applied irrigation water in the first and second

Table 2. Average yield, irrigation parameters and water productivity of corn in the studied farm.

Treatments	Applied irrigation water (m^3/ha)	Reduction of applied water compared to T1 (%)	Yield (kg/ha)	Water productivity (kg/m^3)	Number of irrigations	Irrigation hours
T1	6404 b	0.0	12495 c	1.96 c	14	12
T2	7036 a	-9.9	16503 a	2.35 b	28	5
T3	5334 c	16.7	13668 bc	2.56 ab	23	5
T4	5457 c	14.8	14545 ab	2.64 ab	27	5
T5	4763 d	25.6	12387 c	2.59 ab	22	5
T6	5682 c	11.3	15518 ab	2.72 a	27	5

Table 3. Average yield, applied irrigation water and water productivity of corn in two years of experiment.

Factors	First-year	Second-year	Mean	Conventional values (Shahrokhnia, 2015)
Yield (kg/ha)	15807 a	12565 b	14186	8300
Applied irrigation water (m^3/ha)	5860 a	5699 a	5780	13300
Water productivity (kg/m^3)	2.71 a	2.23 b	2.47	0.70

years was 5860 and 5699 m^3/ha, which was not significantly different. In the second year, yield and water productivity decreased significantly compared to the first year due to poor tillage and low-quality seeds used by the farmer.

Figures 2 and 3 show the relationships of yield and water productivity to irrigation water amount in the treatments. Results show that with the increase of irrigation water, the crop yield increased and water productivity decreased. The relationship of yield to applied water, and water productivity to applied water have a high determination coefficient (R^2). This study shows that tensiometers and infrared thermometers allowed to obtain better results than the other methods. The amount of applied water and crop yield using the Penman-Monteith model (T2) was higher than the other devices, however, the water productivity was lower. In the farmer-managed treatment (T1), the crop yield and water productivity were less than other irrigation scheduled treatments. This may be due to over-irrigation of the cornfield when plants needed less water, and deficit irrigation when plants needed more water.

In the region, yield, irrigation water and water productivity in conventionally managed surface irrigation systems are generally of 8300 kg/ha, 13300 m^3/ha and 0.70 kg/m^3, respectively. In the present study, using

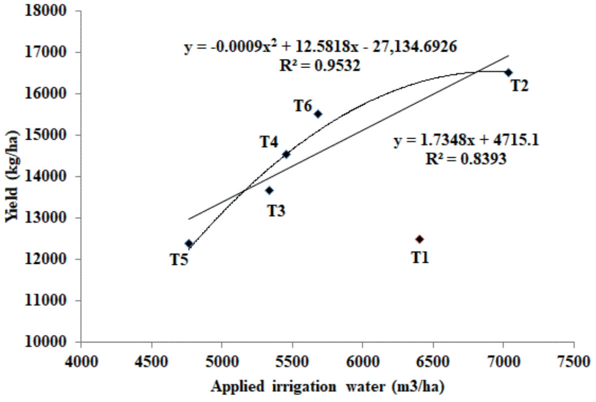

Fig. 2. Yield changes to applied water.

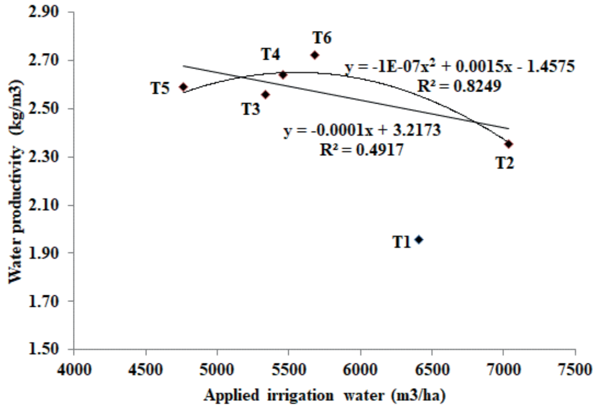

Fig. 3. Water productivity changes to applied water.

Table 4. Results of economic analysis of treatments ($/ha)

Treatments	T1	T2	T3	T4	T5	T6
Irrigation cost	168	140	115	135	110	135
Water cost	224	246	192	192	167	192
Gross income	3587	4607	3993	3993	3587	3993
Device cost	0	0	5	68	57	46
Total cost	392	387	313	395	334	373
Income compared to T1	0	1020	406	406	0	406
Cost difference compared to T1	0	-5	-80	3	-59	-19
Gross benefit compared to T1	0	1025	485	403	59	425
Priority of treatments in terms of gross benefits	6	1	2	4	5	3

irrigation scheduling and under drip irrigation system, these values reached 14524 kg/ha, 5634 m^3/ha and 2.57 kg/m^3, respectively. Therefore, improving surface irrigation system with precise scheduled irrigation using a drip system, may save up to 58% of irrigation water.

Economic analysis results

Table 4 shows the results of economic analysis of irrigation scheduling devices. The gross benefits of T2–T6 were higher than T1. Results show that all irrigation scheduling devices were economically better than the farmer management treatment. T2 and T3 have the highest economic benefit.

Prioritize treatments using the AHP method

To prioritize the treatments based on a set of factors, first, the importance coefficient of the treatments was determined. The criteria of initial price, service and maintenance cost, access to maintenance services, ease of use and accuracy in the results were selected as the most important criteria in decision making. Among the 5 important criteria in farmers' decision making, the accuracy of results was the most important factor to choose the better irrigation scheduling devices. Table 5 shows the criteria weights for selecting irrigation scheduling devices. Table 6 shows the prioritization of irrigation scheduling devices based on the pairwise comparison. After determining the importance of the criteria, their average weight was estimated. The use of tensiometer was the first priority of farmers. However, the use of infrared thermometers and the Penman-Monteith model had also high weights.

Table 5. Coefficient of importance of effective criteria in choosing irrigation scheduling method by farmers.

Criterion type	Criterion weight
Initial price of the device	0.038
The device annual service cost	0.055
Ease of use of the device	0.175
Accuracy of results	0.423
Access to maintenance services	0.309

CONCLUSIONS

The results showed that the five irrigation scheduling devices in this study can be used to increase the water productivity of irrigated corn. Gypsum block allowed to achieve the maximum water productivity. Although the use of the Penman-Monteith model did not allow saving applied irrigation water, however, it increased yield and water productivity. The irrigation water requirement of corn estimated by the Penman-Monteith model was about 7,000 m^3/ha, which is much less than the volume applied in conventional irrigation systems (13,300 m^3/ha). Although the applied water in the Penman-Monteith model was 10% more than other irrigation scheduling devices, it was economically better than the other meth-

Table 6. Priority of choosing irrigation planning method based on pairwise comparison.

Treatments	Weight of the treatment in decision making	Priority of treatments according to the weight of criteria
T2	0.221	3
T3	0.245	2
T4	0.184	4
T5	0.267	1
T6	0.083	5

ods. The water savings compared to conventional irrigation using the infrared thermometer, soil moisture meter, tensiometer and gypsum block were between 11 to 26%, which were statistically significant ($p<0.05$). The applied irrigation water in the treatment with the tensiometer was lower than in the other treatments.

In terms of ease of use, the Penman-Month model has received more attention from farmers in the region. The farmer selected the accuracy of irrigation scheduling devices in estimating required water as the most important factor. If only economic criteria are considered, the use of the Penman-Monteith model had the highest priority. However, considering all the criteria, priority is given to the use of a tensiometer, followed by the management operating with the infrared thermometer and the Penman-Monteith model. The average water productivity had increased from 2 kg/m^3 in the farmer-managed treatment to about 2.7 kg/m^3 (using gypsum block) which shows an increase of 35%.

In this study, corn applied irrigation water reached 4800-5700 m^3/ha (11-26% water saving) using both the drip irrigation system and the irrigation scheduling devices. Compared to the applied water in conventional irrigation management (13300 m^3/ha), the water-saving reaches 57 to 64% which is very significant. Water productivity of corn under conventional surface irrigation systems in the region is generally lower than 1 kg/m^3. The water productivity in the farmer-managed treatment in this study was about 1.96 kg/m^3. In other words, replacing the conventional surface irrigation systems with a well-managed drip irrigation system can significantly increase the water productivity of corn.

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