RESEARCH PAPER

In-field assessment of smallholder irrigation systems in southern Tunisia

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Abstract

As many countries of Mediterranean basin, Tunisian water resources becomes limited and insufficient to satisfy different competing demands. Agriculture currently uses beyond 80% of total available resources. As water is the most critical resource for sustainable development notably in agriculture, the need for a consistent rational management of this resource has become needful. Furthermore the irrigation efficiency remains very low, only 55% of applied water is used by crops. Increasing the water use efficiency is essential to overcome water shortage in these conditions of climate change. The present paper is devoted to analyse some irrigation efficiency data after more than two decades efforts to modernize irrigation and improving its efficiency. These data were collected from private farms located in Djorf peninsula which is a part of south arid region of Tunisia. It is a very sensitive area to climatic hazards where resources are scarce and the aquifer is threatened by the risk of seawater intrusion. A series of irrigation events and farmers practices were observed. Applied volumes of water was measured and compared to the peak ETo of the season. Information regarding irrigation practices (frequency, sowing date, soil tillage and amendment) was collected. Calculations showed that in some cases, mean daily water supplies reach twice the daily peak evapotranspiration. In fact, to avoid any stress to their crops, farmers supplies large amounts of water exceeding irrigation needs and leaching requirements. As soils has sandy texture, a good part of supplied water percolate deep beyond the root zone of crops. Although this water helps leaching, its amount far exceeds leaching requirements. At the field level, some other irrigation efficiency parameters were measured. Conveyance efficiency is excellent because water source point is always near irrigated field, application efficiency ranges from 22 to 100 %. The general average of storage efficiency was of 59%.

Keywords: arid, irrigation efficiency, climate, soil, water use efficiency, evapotranspiration.

Evaluation de la gestion de l'eau a la parcelle de la petite irrigation au sud Tunisien

Résumé

Comme de nombreux pays du bassin méditerranéen, les ressources en eau en Tunisie deviennent limitées et insuffisantes pour satisfaire les demandes des divers secteurs concurants. L'agriculture utilise actuellement au-delà de 80% du total des ressources disponibles. Comme l'eau est la ressource la plus critique pour le développement durable notamment dans l'agriculture, la nécessité d'une gestion rationnelle de cette ressource est devenue nécessaire. En effet, l'efficience de l'irrigation demeure très faible et seulement 55% de l'eau appliquée est utilisée par les cultures. L'amélioration de cette efficience est essentielle pour surmonter la pénurie d'eau dans ces conditions de changement climatique. Le présent papier est consacré à l'analyse des données relatives à l'efficience de l'irrigation après plus de deux décennies d'efforts pour sa modernisation et l'amélioration de son efficience. Ces données ont été recueillies dans des fermes privées situées dans la péninsule Djorf qui se situe dans la région aride du sud de la Tunisie. C'est une zone très sensible aux aléas climatiques, où les ressources sont rares et l'aquifère est menacée par le risque d'intrusion d'eau salée. Une série d'événements d'irrigation et des pratiques paysannes ont été observées. Les volumes appliqués d'eau ont été mesurés et comparés aux valeurs de l'évapotranspiration de pointe (ETo) de la saison. Les informations concernant les pratiques d'irrigation (fréquence, date de semis, travail du sol et des amendements) ont été recueillies. Les calculs ont montré que dans certains cas, la moyenne de l'apport quotidien de l'eau par irrigation atteint le double de l'évapotranspiration de pointe. En fait, pour éviter tout stress pour leurs récoltes, les agriculteurs fournissent de grandes quantités d'eau dépassant les besoins d'irrigation et les exigences de lessivage. Comme les sols sont de texture sableuse, une bonne partie de l'eau fournie percole en profondeur au-delà de la zone des racines des cultures. Bien que cette eau aide au lessivage des sels, sa quantité dépasse de loin les besoins de celui-ci. D'autres paramètres d'efficience de l'irrigation ont été mesurés. Ainsi l'efficience du réseau de transport était excellente parce que le point d'eau est toujours proche des parcelles irriguées. L''efficience de l'application varie de 22 à100%. La moyenne générale de l'efficacité du stockage était de 59%.La fraction moyenne de lessivage était de l'ordre de 33% et variait entre 0 et 68%.

***Mots-clés:** arides, efficience de l'irrigation, climat, sol, l'utilisation efficiente de l'eau, évapotranspiration.*

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1. INTRODUCTION

Agriculture is the main food source for world population. It ensures through irrigation over a third of global agricultural production (UN-WWAP, 2006). This production is reached by only 17% of total agricultural land which allows considering it as very productive (ICID 2003). The cost of this productivity is 70% of available fresh water resources. However, in future, irrigated area will be expected to produce more to meet the needs of a world population growing continuously.

In these circumstances, water remains the most determining factor of production both in quantity and quality. Major challenge of irrigation in the future is to find ways to increase production while using the same water resources even less available because of water scarcity constraints imposed by climate change through more frequent droughts. Results of these changes are manifested in more imbalances between rainfall and crop needs during their growing season. This disparity also has a considerable impact on yields and quality of agricultural products. Since irrigation has always been the basic mean for maintaining an optimal production, its better practice to promote water conservation will become indispensable.

In the arid part of Tunisia, as in many countries of Mediterranean basin, groundwater is the main provider source for all demands. The replenishment of aquifers by harvesting of surface water is a fact frequent in arid and semi-arid zones (Ammami, 1984). In the study area, water resources come from shallow ground water where the overexploitation already starts to be felt. These resources are used in irrigation which is practiced by individual shallow wells .The salinity ranges from 3 to 8 g / liter. As the number of shallow wells has become important in recent decades, the overexploitation led to a general increase in salinity which becomes more important during drought.

In last decades, significant efforts have been made for modernizing irrigation and improving its efficiency. The beginning was with the project «TUN 91 / 002-UNDP « which intended for improving surface irrigation systems through buried PVC networks that have significantly contributed in reducing seepage and percolation during transport of water from the source to irrigation units. On the other hand, an encouragement to conversion to drip was initiated through legislation that allows smallholder farmer to receive funding up to 60% of drip materials and equipment cost (Thabet, 2008). These measures contributed in reducing lost volumes by evaporation and deep percolation. However the problem persists in water supplied to irrigated cultures which far exceed their needs and leaching requirements. Main cultivated crops are those tolerant to salinity. In summer, farmers grow millet (Pennisetum glaucum), pepper (Capsicum annuum. L) and some cucurbits. In the winter, they grow Barley (Hordeum vulgare L.), carrots, onion and some leafy vegetables. Products are usually sold in the local market. As these products are organic, they are highly sought by consumers.

Outside oases, irrigated agriculture consists of small green islets scattered in the large steppe area or in combination with extensive olive groves. Each family farm is mostly equipped with its own water source usually a shallow well which is usually inside or nearby the irrigated land. Water is pumped to a tank which is built at the highest point to ensure gravity flow to each part of irrigated area in the farm.

Irrigated area is divided into small borders or basins of some square meters surface and surrounded on all boundaries by a low dike. This irrigation system uses low flow rates supplied to level soil surface over a sufficient period of time to cover whole irrigated border or basin according to the visual assessment of the farmer.

The small size of borders and basins is imposed by soil texture and low available flow rates. Sandy soils generate high infiltration ratio and hinder the progress of the wetting front especially with low flow rates. A bad soil grading is generally associated to these factors. In order to correct water's distribution inequality, generally the farmer continues the irrigation time although this solution generates considerable losses by deep percolation and a low coefficient of uniformity of irrigation (Thabet, 1997). The present study tries to assess the impact on some irrigation efficiency parameters and water resources after two decades of project's implementation.

2. MATERIALS AND METHODS

2.1. Study Area

As indicated in figure 1, Djorf's peninsula is administratively part of the governorate of Médenine. It is located in the arid part of the country. It is characterized by low and erratic rainfall. It is it is a famous olive area. Irrigated vegetable crops are associated with olive trees in a small family agriculture.

2.2 Climate

As in other arid parts of the country, the amount and

Figure 1: Study area location

distribution of precipitation events are uneven and vary greatly from year to year. Water balance lags a deficit almost the year. Only during winter months we record sometimes a positive balance. Summer temperatures are very high, evapotranspiration rate is important. During their cycle, crops require a lot of water because an insufficient water supply may reduce crop production and quality (Debaeke and Aboudrare, 2004; Smittle et al., 1994). Figure2 summarizes values of the calculated daily potential evapotranspiration (Thabet, 2009) for a series of more than thirty years of nearest station data (Médenine) by different formulas: Hargreaves-Samani (1985); FAO-Penman (1948); Riou (1980) and Blaney-Criddle (1950).

The figure above shows that for three of the four models, peak evapotranspiration is in July. It varies from 7.07 to 8.10 mm/day. We note that the values start to become important from April.

2.3 Soils

Soils are sandy soil with low organic matter content. The total soil available water calculated between field capacity (FC) and permanent wilting point (WP) for an assumed root extracting depth of 0.50 m for vegetables crops was 75 mm.

Result of particle size analysis of samples taken from three profiles at three level's depth (0-20cm; 20-40 cm; 40-60 cm) is reported in table 1. It shows that soils are loamy sand and the sand fraction represents around 80%. This texture influences many soil's physical characteristics as infiltration rate, water holding capacity, internal drainage …etc.

2.4. Flow measurement

To evaluate different water use efficiencies, a measurement campaign was undertaken during a month (April) in a representative farm of the general typology of the area. Some data were collected by field measurements such as flow rate, applied volumes and dimensions of the irrigation units, while others, the interview with the irrigator is the source as the irrigation period for example, sowing or planting date and fertilizers application.

The flow rate (Q) was estimated by measuring the time (T) required to fill a container of a known volume (V). Measurement was repeated three times and flow is generally expressed as:

Where:

$$Q[L^3 * T^{-1}] = \frac{V[L^3]}{[T]}$$

Q: flow liter per second (l / s);

V: volume in liters (l);

T: time in seconds (s).

2.5. Measurement of the applied irrigation water

Irrigation water supplies depend on the soil water holding capacity (SWHC) which is a very important agronomic characteristic. Soils that hold important amounts of water are less subject to leaching losses of applied nutrients or pesticides. This is because a soil with a low water holding capacity (i.e. a sandy loam) reaches the saturation point much earlier than a soil with a higher water holding capacity (i.e. a clay loam). For these soils, it is advisable to irrigate frequently but with small amounts of water.

After a soil's saturation, the excess water and some nutrients and pesticides in the soil solution are leached downward in the soil profile beyond the roots. A good management of the irrigation time application is a key factor for its success.

During an irrigation event, with a known flow, monitoring of the application time can deduce the amount of applied water. In fact, components of the irrigation are governed by the basic equation (2).

$$Q[L^3 * T^{-1}]*[T] = D[L]*S[L^2]$$

Where:
Q = flow (L / s);
T = time application of irrigation (s);
D = applied amount of water (mm);
S = surface area (m^2).
From equation (2) applied amount D is deduced by:

$$D\ (mm) = \frac{Q(L/s)*T(s)}{S(m^2)}$$

3. RESULTS AND DISCUSSION

Basic data collected during irrigation monitoring are reported in table 2 which shoes that measured flow rates range from 1 to 3 liters per second. Irrigation frequency goes from two to fifteen days. Applied amount of water vary 2.7mm to 69.33mm. In following, we will study some irrigation's assessment parameters.

3.1. Conveyance Efficiency

Conveyance efficiency (E c) is the ratio of water delivered to the total water diverted or pumped into an open channel or pipeline at the irrigated field. It is expressed as a percentage and includes seepage losses and evaporation. In the study area, almost farms are equipped with buried poly–vinyl chloride (PVC) pipeline system (figure 3) which has been installed as a part of a national project on the assessment of water use in irrigated agriculture. The water lost between the source and point of use is much reduced and smallholders have good conveyance efficiency.

3.2 Daily equivalent applied water

The histogram of applied amount of water for each irrigation event is represented in Figure 4. It shoes that applied water far exceed peak evapotranspiration in most cases. The irrigation ration can reach up to four times peak evapotranspiration. Under irrigations are recorded in the case of millet where a low frequency is practiced by farmers.

Table 1: Particle size analysis results

Sample n°	1_1	1_2	1_3	2_1	2_2	2_3	3_1	3_2	3_3
Clay (%)	5.5	1.25	1	5	5	1	4.75	3	3
Silt (%)	4.75	165	12.5	9.25	11	22.5	5.75	6	17
Total Sand (%)	88.35	78.05	82.1	81.65	82.8	74.25	84.65	87	73.4

Table 2: Collected irrigation data:

Irrigation event	Crops	Flow (l/s)	Applied water (mm)	frequency (day)	Daily average (mm)
1	Pepper	2	69,33	3	23,1
2	Pepper	2	53,33	3	17,8
3	Pepper	2	41,6	3	13,9
4	Pepper	2	64	3	21,3
5	Pepper	2	120	3	40
6	Pepper	2	33,2	3	11,1
7	Pepper	2	38	2	19
8	Pepper	2	50	2	25
9	Pepper	0,5	50	2	25
10	parsley	3,33	44,4	2	22,2
11	parsley	3,33	39,96	2	20
12	parsley	3,33	59,94	2	30
13	parsley	3,33	47,45	2	23,7
14	Onion	3,33	52,23	5	10,4
15	Onion	3,33	58,28	5	11,7
16	Onion	1,25	62,5	5	12,5
17	Millet	1,25	61,5	7	8,8
18	Millet	1,25	50	7	7,1
19	Millet	1,25	40	7	5,7
20	Millet	0,25	18,75	7	2,7
21	Watermelon	2	61,03	7	8,7
22	Watermelon	2	54,17	7	7,7
23	Onion	1	25,28	5	5,1
24	Onion	1	21,89	5	4,4
25	Millet	3,33	68,18	15	4,5
26	Millet	3,3	55,54	15	3,7
27	squash	1	29,67	4	7,4
28	squash	1	54,98	4	13,7

3.3Water application efficiency

Application efficiency was defined by many researchers, its expressions varies slightly between them (Jensen et al., 1983; Walker and Skogerboe, 1987; Solomon, 1988; Burt et al., 1997). The main concept of application efficiency is the percentage of water delivered to the field and ready for crop use.

The application efficiency measures how efficiently water has been applied to the root zone of the crop, it relates the total volume of water applied irrigation to the volume of water contained in the root zone and is available for use by the crop. So in general it can be expressed as the ratio between the depth of water stored in the root zone and the average depth applied.

$$E_a = \frac{W_c}{W_a} * 100$$

Where:

Ea = application efficiency (%);

Wc: water stored in root zone (available for use by crops);

Wa: water applied in the field.

In application of equation 4, data performed by excel software are shown in figure 5.

From this figure, it can be seen that calculated application efficiency ranges from 22 to 100 %. As application water efficiency gives a general sense about irrigation practice, we can meet cases with high Ea but irrigation water is poorly distributed that crop stress can exist in some areas of the field. It is also possible to have an Ea near to 100% but soil profile is not filled sufficiently to meet crop water requirement. In our study, we notice this for low frequency irrigation and under watering supply where water application efficiency can reach 100%. So this factor alone cannot be sufficient to assess irrigation quality.

3.4 Storage efficiency

Storage efficiency measures the percentage of water stored in the root zone in relation to the maximum storage capacity of the soil (Irmak and al.2011). It is used as a tool to evaluate the performance of surface irrigation (Howell, 2003). It is generally defined as follows (Irmak et al, 2011; Howell. 2003):

$$E_s = \frac{Volume\ stored\ in\ root\ zone\,(V_s)}{Soil\ moisture\ deficit\,(V_{rz})}$$

Vs : volume of water stored ;

V rz: maximal volume which can be stored.

The general average of the storage efficiency is of 59%. It depends on irrigation frequency of and applied amount of water that is why calculated values ranges between 14 and 100%.

3.5 Irrigation efficiency:

Irrigation efficiency is defined as the percentage of water delivered to the field and used beneficially .It can be expressed as:

$$E_i = \frac{W_b}{W_d} * 100$$

Where:

Ei = irrigation efficiency (%);

Wb: water used beneficially by crops;

Wd: water delivered.

Irrigation efficiency is broadly defined than application efficiency in that irrigation water can have other uses than to satisfy crop water requirements (Jensen, 2007). In arid lands conditions, the other essential role that can have irrigation water is leaching of salts because of its TDS which generally range between 3 and 7g/liter. So beneficially used water includes crop water requirements and leaching requirements.

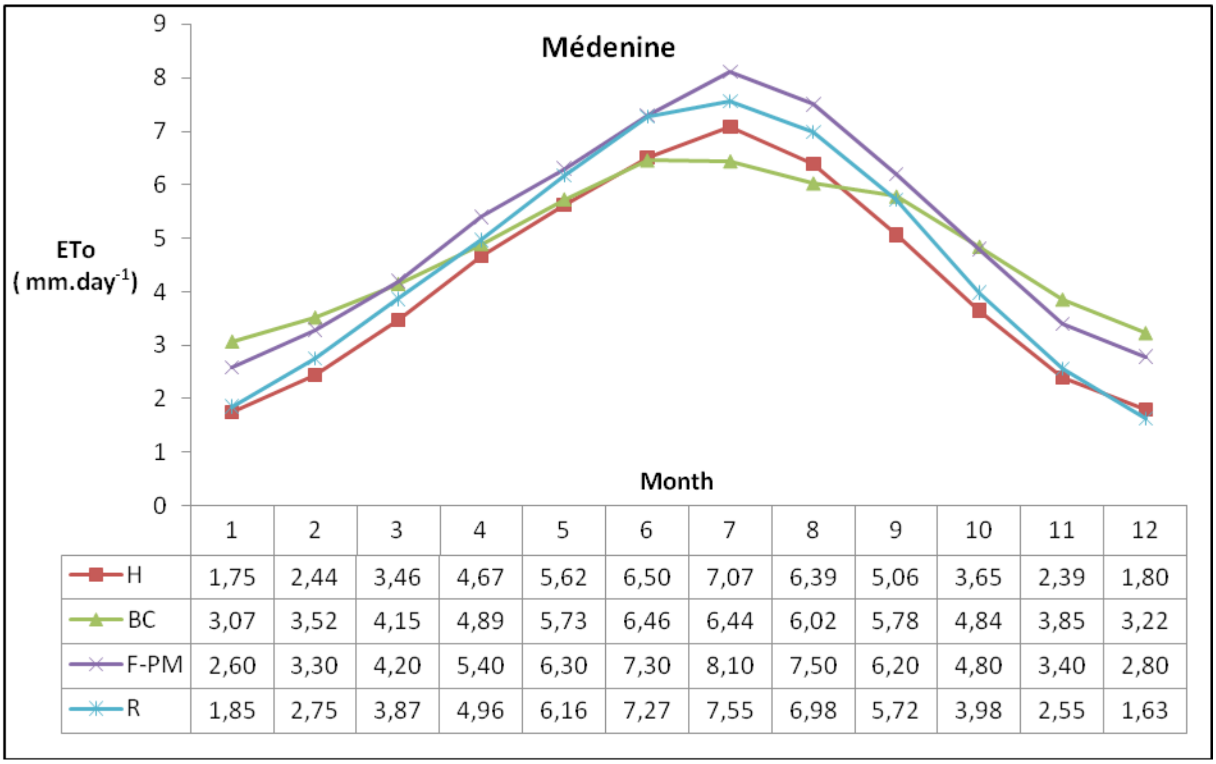
The second term is generally calculated to maintain soil salinity at a level that allows optimal production. This requires laboratory analyzes that cannot always achieved. If we consider that water amount which is not stored in root zone is deep percolated and so can be considered as leaching fraction, deep percolation ratio can be expressed as:

$$DPR = 1 - Ea$$

With this hypothesis, the average of leaching fraction will be 33% and ranges from 0 to 68%. In arid conditions, this rate is important because most cultivated crops tolerate salinity. On other hand, excess percolated water can leach needed nutrients and in some cases cause waterlogged growing conditions.

CONCLUSIONS

As agriculture is the most consumer water sector, the challenge is to reduce the amount of water used without affecting agricultural productivity. Smallholder irrigation systems occupy more than a third of the irrigated areas in Tunisia (Al Atiri, 2005). In the arid part of the country, farm sizes generally range from a fraction of a hectare to few hectares, the water source



	1	2	3	4	5	6	7	8	9	10	11	12
H	1,75	2,44	3,46	4,67	5,62	6,50	7,07	6,39	5,06	3,65	2,39	1,80
BC	3,07	3,52	4,15	4,89	5,73	6,46	6,44	6,02	5,78	4,84	3,85	3,22
F-PM	2,60	3,30	4,20	5,40	6,30	7,30	8,10	7,50	6,20	4,80	3,40	2,80
R	1,85	2,75	3,87	4,96	6,16	7,27	7,55	6,98	5,72	3,98	2,55	1,63

Figure 2: Monthly evapotranspiration data (mm) calculated by different formulas.

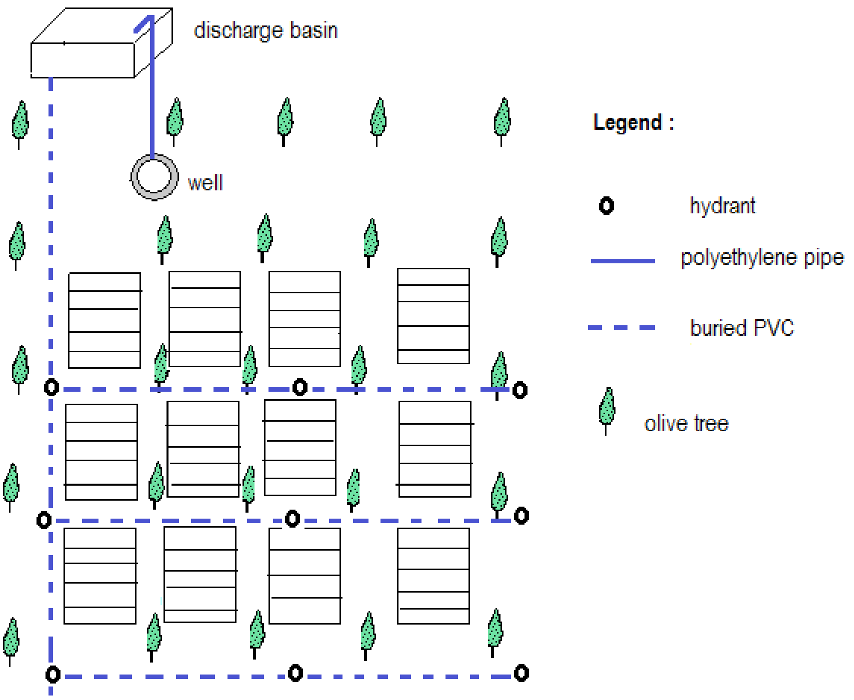


Figure 3: Hydraulic structure of the farm in olive grove.

is usually near irrigated field which reduces losses during conveyance. The main challenge is to improve water use practices at irrigated field level as crops water requirements estimation and irrigation scheduling. Collected data showed that applied amount of water is not governed by any rule. This is because it is difficult for a farmer to tell at any given moment if there is a water deficit or not . Since over irrigation usually does not cause harm, farmers tend to "play safe" and increase irrigation amount in order to avoid water stress.

To ensure best management of available water resources in these conditions, a set of efficient management practices concerning water, soil and crops should be adopted:

- Promoting water-use efficient techniques: because moisture availability for growing crops is the most significant factor limiting production in dry areas as localized irrigation which is widely recognized as one of the most efficient methods of watering crops ;
- Soil tillage: hoeing improves soil structure and infiltration rate, with narrower row spacing it can significantly reduce the amount of water evaporated from the soil surface.
- Organic amendment: a good organic amendment improves soil fertility and soil water retention capacity;
- Weed controls which compete for water, nutrients and light at the cost of lower yields for the crops.

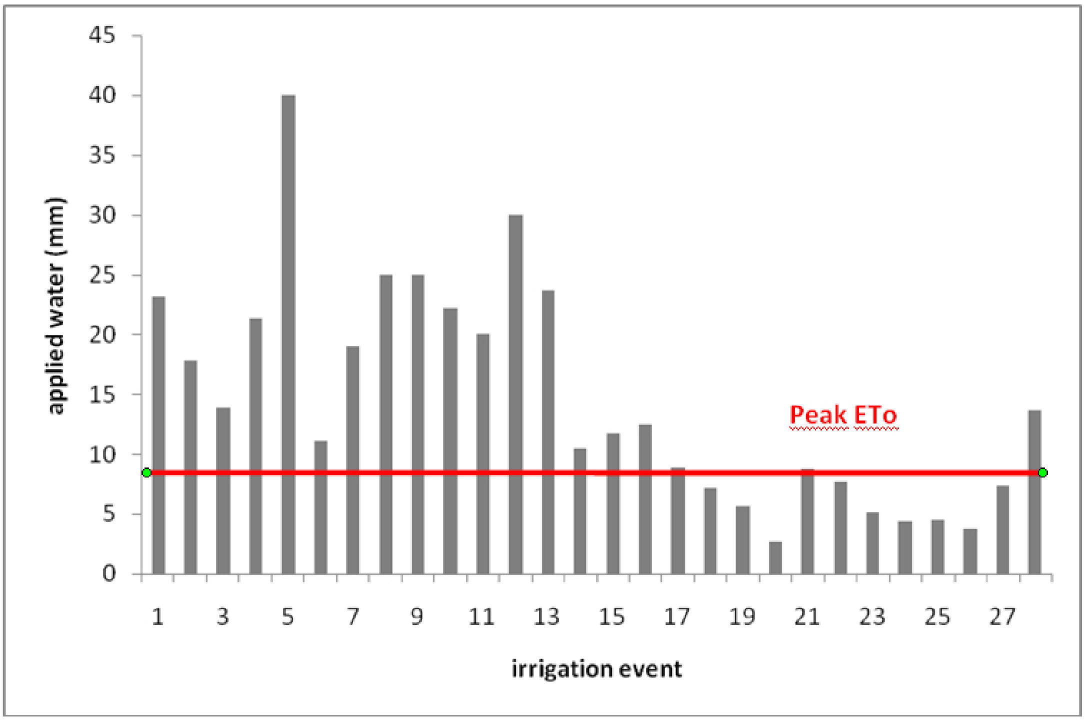


Figure 4: Daily water supplies average (mm).

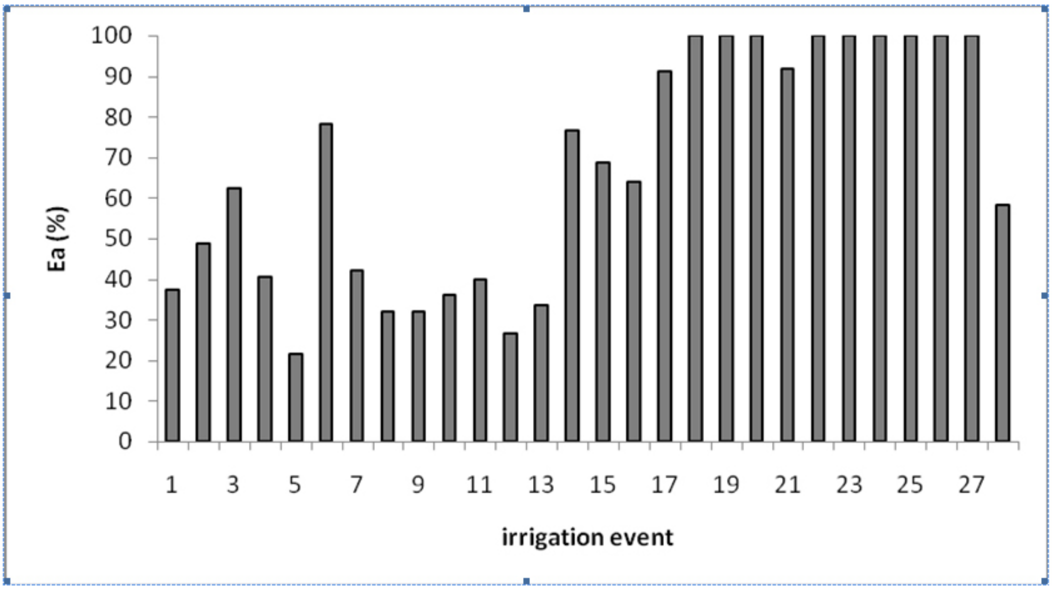


Figure 5: Application efficiency (%).

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