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MODERNIZATION DRIP IRRIGATION SYSTEMS TO IMPROVE FODDER CROPS PRODUCTION AND RATIONALIZING GROUNDWATER IN NORTH SINAI - EGYPT: CASE STUDY

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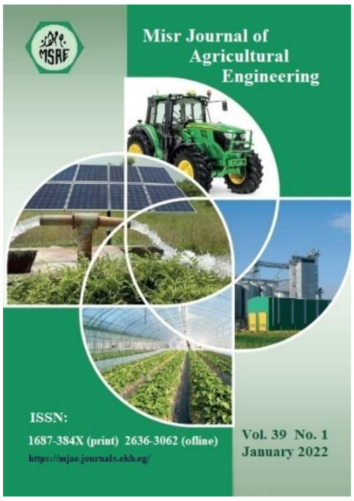

Keywords:
Drip irrigation;
Fodder crops production;
Rationalization groundwater and operational energy.

ABSTRACT

Field experiments were carried out at Romana and Bir Elabd villages, North Sinai Governorate at three sites each village, cultivated by forage pearl millet and fodder beet crops during summer 2015 and winter 2015/2016, respectively. To evaluate the effect of updating drip irrigation system design (D_I) with two water application levels:100 and 75% from actual crop water requirements (ET_c) designated T_{100} and T_{75}, respectively, and comparing with the drip systems used by farmers for irrigation (D_C) under sites conditions. The parameters were statistical distribution of drippers flow rates, water application efficiency "Ea%", low-quarter distribution uniformity "DU_{lq}", fresh and dry yield seasonally, water use efficiency upon fresh "WUE_f" and dry yield "$WUEE_d$", and energy use efficiency upon fresh "EUE_f" and dry yield "EUE_d". The most important results were: good performance of D_I through excellent functioning of a statistical distribution of dripper flow rates. The highest mean values of Ea%, DU_{lq}, $IWUE_f$, $IWUE_d$, EAE_f, and EAE_d were recorded by D_IT_{75} treatments at both seasons, in all sites. Total fresh and dry yield by D_IT_{100} treatments recorded the highest mean values at both seasons, between all sites. Also, the mean values of water-saving percentages compared with Dc treatment between all sites were 34.5 - 29.8% by D_IT_{75} and 13.8 - 9.8% by D_IT_{100} in summer and winter seasons, respectively, whereas, the mean values of operating energy saved percentages were obtained 33.2 - 35.5% by D_IT_{75} and 20.6 - 23.2% by D_IT_{100}.

1. INTRODUCTION

Egypt faces water deficiency and climate change can have several kinds of impacts on the agricultural sector and stability of food security. **Attaher *et al.*, (2010)** evaluated some proposed adaptation measures to overcome the projected impacts of climate change over on-farm irrigation systems in Egypt. Improve irrigation systems efficiencies, change irrigation systems, and deficient irrigation was evaluated by using the multi-criteria approach of evaluation. Adaptation measures were studied under current climate conditions and climate change projections of the Intergovernmental Panel on Climate Change, **(IPCC, 2014)** series of emission scenarios (SRES) for years 2025s, 2050s, and 2100s, They concluded that switching to drip irrigation system had the best impact on improving crop yield, and it could be strongly recommended as an efficient adaptation measure, under conditions of economical and power resources availability. Therefore low-power requirements irrigation systems could be better selections in the future. The climate change impacts on crop water requirements, under Egyptian conditions, have been studied in scattered and limited studies **(Sowers *et al.*, 2011 and El-Shirbeny *et al.*, 2018)** and most of these studies were focusing on specific regions in Egypt and specific crops.

Global climate change models have been used in Egypt to develop climate change scenarios to quantify the risk of climate change on wheat and maize production in Egypt, **(Ouda *et al.*, 2013)**. Modern irrigation technology not only benefits individual farmers but could also be beneficial for the national economy by increasing the productivity of land units and achieving optimal use of social resources, **(Ali *et al.*, 2020)**. While the trickle (drip) irrigation system has great potential for high irrigation efficiencies, poor system design, management, or maintenance, can lead to low efficiencies. The emitter type, water quality, and emitter interspacing are the crucial factors affecting the hydraulic performance of drip irrigation systems. Irrigators to overcome this lack of uniformity found it necessary to over-irrigate, **(Elamin *et al.*, 2020)**. Over-irrigation can lead to the waste of water, nutrients, and energy as well as the possibility of groundwater contamination due to excessive leaching. **(Evans *et al.*, 2007)** mentioned that with trickle irrigation, salinity control is influenced by the quality and quantity of the applied water, the irrigation system and its management, drainage conditions, and agronomic techniques, these factors are often interrelated so that the solution to the salinity, the problem may not be obvious without proper diagnosis. The high irrigation frequency might provide desirable conditions for water movement in soil and uptake by roots, (**Rafie and El-Boraie, 2017**). The optimal design and managing of irrigation systems at the farm level is a factor of the first importance for rational use of water, economic development of agriculture, and its environmental sustainability, **(Holzapfel *et al.*, 2009)**. All the performance parameters including manufacture coefficient of variation, hydraulic design coefficient of variation, and their combined coefficient of variation values indicated that pressure-compensating emitters remain in the excellent category, **(Nazeer, 2010)**. The use of micro irrigation systems is expected to result in water savings, and increased crop yields in terms of volume and quality, (**Goyal, 2016).** By using drip irrigation systems with a lateral length of 30 m and with a slope 2% downhill for increasing the water application efficiency, decreasing the friction losses along lateral lines, and lead to saving more water head energy, (**Attia *et al.*, 2019)**. Operational energy is one of the highest components of the life cycle energy consumption along with the initial embodied energy of the irrigation system. Which the energy-consuming features of the irrigation system were divided into four basic areas: Operating energy; manufacturing energy; transportation energy; and installation energy. Operational energy is the energy required to operate the irrigation system throughout its entire life durability, **(Diotto *et al*., 2014)**.

Objectives of this study were to:

- Evaluating the technical and practical aspects of the forms of drip irrigation systems used by local farmers,

- Updating drip irrigation systems in terms of redesign, components, scheduling, and rationalizing operating energy consumed, and
- Maximizing the production of water unit by producing fodder crops in light of climatic changes and marginal conditions of the study areas.

2. MATERIALS AND METHODS

Romana and Bir Elabd villages, North Sinai Governorate, were selected and considered three experimental sites in each village: S1, S2, and S3 in Romana, and S4, S5, and S6 in Bir Elabd, the locations are shown in **Table (1)**.

Table (1): Locations of considered experimental sites

site # village	Latitude	Longitude
S1 Romana	32°44'52.34"N	32°44'52.34"E
S2 Romana	30°58'1.38"N	32°45'50.86"E
S3 Romana	30°58'17.80"N	32°45'28.20"E
S4 Bir Elabd	30°58'55.95"N	33° 2'54.13"E
S5 Bir Elabd	30°59'2.14"N	33° 3'25.90"E
S6 Bir Elabd	30°58'56.89"N	33° 3'14.55"E

Some soil physical analyses were determined according to **(Klute, 1986)** as shown in **Table (2).** Some soil chemical analyses were determined according to the methods described by (**Black, 1965)** as shown in **Table (3).** The mean values of some chemical properties of the irrigation water are presented in Table (4). No water table was observed in all sites.

Table (2): Mean values of some soil physical properties along 60 cm of soil depth profile at considered sites.

Site	Coarse Sand	Fine Sand	Silt	Clay	Texture class	FC	WP	AW	HC	OM	Bd	P
	(%)					(w%)			(cm h^{-1})	(%)	(gcm^{-3})	(cm^3 voids cm^{-3} soil)
S1	8.6	77.5	8.4	5.5	Sandy	14.0	6.0	8.0	6.85	0.15	1.68	0.36
S2	8.6	77.4	8.7	5.3		14.5	6.0	8.5	6.97	0.21	1.66	0.36
S3	8.8	77.6	8.6	5.0		14.0	6.0	8.0	7.55	0.26	1.67	0.36
S4	8.5	76.5	8.6	6.4		14.9	6.0	8.9	6.80	0.18	1.65	0.35
S5	8.9	76.0	8.8	6.3		14.0	6.0	8.0	6.30	0.19	1.65	0.35
S6	7.9	75.4	11.6	5.1		15.7	6.0	9.7	7.28	0.23	1.63	0.38

FC, Field capacity; WP, Wilting point; AW, Available water; HC, Hydraulic conductivity (cm h^{-1}); OM, Organic matter (%): Bd, Bulk density (g cm^{-3}); and P, Porosity (cm^3 voids cm^{-3} soil).

Seeds of Egyptian pearl millet local cultivar (Shandweel-1) cultivated in 26th. April 2015 and fodder beet seeds (Beta vulgaris L. Monovert) cultivated in 1st. October 2015 as winter season 2015/ 2016. The spacing of plants in the same row (holes) was 0.2 m for pearl millet and it was 0.3 m with fodder beet (traditional spacing in Egypt). However, soil preparation practices were similar for the two crops.

Soil management practices:

The soil management practices under conventional management and drip irrigation system (DC) by local farmers without any engineering basis in each cultivated season were applied. While soil management under an improved drip irrigation system (DI) according to some basis of selecting materials and technical equipment was applied. According to **(Rafie and El-Boraie, 2017)** the soil preparation practices were applied each season. Ammonium nitrate was added through irrigation water according to the methods of **(El-Sarag, 2013) and (Abdelraouf et al., 2013)**. Other agriculture practices were conducted according to the recommendations of the Ministry of Agriculture and Land Reclamation. Some properties of the applied plant residues compost (PRC) are represented in **Table (5)**.

Table (3) Mean values of some soil chemical properties along 60 cm of soil depth profile at considered sites.

Site	pH 1:2.5	EC (dS m^{-1})	Soluble Cations (meq L^{-1})				Soluble Anions (meq L^{-1})			Total N (%)	Ava. P (ppm)	Exch. K (meq.100g $soil^{-1}$)
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{--}			
S1	7.16	3.87	17.26	7.59	13.27	0.54	3.56	18.10	17.01	0.71	0.12	8.00
S2	7.08	3.77	18.56	6.42	12.11	0.62	3.05	18.39	16.28	0.78	0.14	9.10
S3	7.16	3.48	16.84	6.07	11.30	0.54	2.62	18.16	13.97	0.82	0.10	11.20
S4	7.25	3.56	17.61	7.79	9.69	0.53	3.13	18.78	13.70	0.88	0.19	13.10
S5	7.25	3.91	19.31	8.72	10.58	0.49	2.70	21.65	14.74	0.83	0.14	10.35
S6	7.26	3.99	21.58	6.61	11.25	0.48	2.72	21.46	15.74	0.60	0.15	12.22

Table (4) Mean values analysis of some chemical groundwater properties at considered sites.

Site	pH	EC	TDS	Soluble Cations				Soluble Anions				
				Na^{+}	K^{+}	Ca^{++}	Mg^{++}	CO_3^{-}	HCO_3^{-}	Cl^{-}	SO_4^{--}	NO_3^{--}
		(dS m^{-1})	(mg L^{-1})	(mg L^{-1})								
S1	7.1	4.07	3221.0	1547.5	135.6	542.4	376.1	3.2	114.1	2038.6	389.8	55.9
S2	6.9	3.36	2836.8	1324.4	129.5	391.8	305.3	2.9	113.4	1639.8	339.5	55.4
S3	7.0	3.44	2722.8	1266.2	117.9	486.9	332.4	2.5	114.0	1671.7	367.8	47.4
S4	7.2	3.63	3010.0	1357.5	103.0	483.1	380.4	2.9	100.5	1861.3	323.7	35.6
S5	7.2	4.70	3584.0	1771.9	142.5	602.7	488.0	3.8	134.4	2337.7	465.6	63.6
S6	7.2	4.75	3671.9	1899.2	136.0	535.5	467.5	3.3	130.3	2455.0	386.4	63.2

Table (5): Mean values for some compost properties.

Stability or Maturity	pH	EC (dS m^{-1})	D_b* (g cm^{-3})	O M (%)	Total O C (%)	Total N (%)	C:N ratio	WHC (w%)	Fineness 2.0-0.5 mm (%)	Fineness 0.5-<0.1 mm (%)
Mature	7.43	2.11	0.66	61.32	33.67	2.17	15.52	117.5	40.22	59.78

*D_b, Bulk density: WHC, Water holding capacity: OM, Organic matter; O C, Organic carbon.

Description of adjustment drip irrigation system (D_I):

Adjustment surface drip irrigation systems as re-design, adding some selecting materials, and technical equipment and management (D_I) were applied and compared with commonly installed drip systems (D_C) by farmers as conventional irrigation methods. In each site of (D_c) were connected to the flow meter throughout the supplied line to record the amounts of water used during cultivated seasons. The improved surface drip irrigation (D_I) showed in **Fig. (1)**. The additional tools by re-design, which includes: main control head unit located beside the source of groundwater well, and includes: electrical centrifugal pump operated by an electrical motor 2.25 horsepower and the discharge 7.0 $m^3 h^{-1}$ at 25 m head, non-return valve, venturi fertilizer injector of one-inch diameter, disk screen filter 2 inches (120 mesh), and 63 mm diameter PE hose as the mainline connected with two manifolds supplying water to each subplot by the water application level:100 and 75% from actual crop water requirements (ET_c) designated as T_{100} and T_{75}, respectively. The laterals of 16 mm P.E tube GR drippers built-in line (3 drippers m^{-1}) with an average flow rate of 3.8 L h^{-1} each dripper at 12 m head. The length of laterals was 33 m. Separate valves with corresponding flow meters were installed to track the amount of water applied per irrigation subplots. The soil surface slope was 1% in the run direction of laterals and spacing was 0.75 m as furrows for planting seeds in two plant rows (0.25 m between them) for each lateral line.

The experiment design in each site was a randomized complete block design (RCBD) with four replications having a split-plot arrangement and each replicate contained three laterals. The experiment area was 594 m^2 (18 x 33m) divided into Two equal subplots representing the levels of irrigation water treatments of 100, and 75% of water requirements denoted as T_{100}, and T_{75}, respectively. Each subplot 297 m^2 (9 x 33 m) represented 12 ridges.

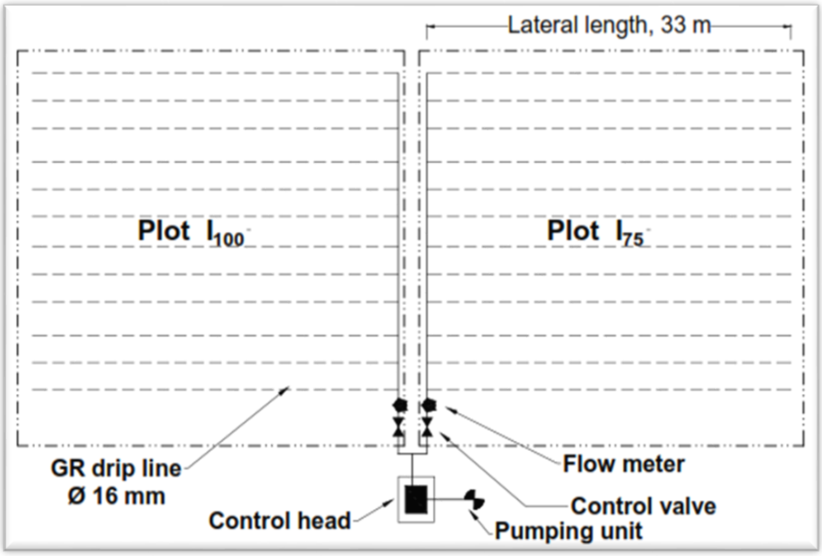

Fig. (1) The experiment layout in each considered site (Not to scale)

Estimation of water requirements:

The irrigation water is applied when the available soil moisture content is depleted in the upper 60 cm of the soil profile in order to raise the soil moisture content to field capacity. Data presented in Table (6) showed the ET_o under North Sinai meteorological conditions using the methodologies formulated by **(Allen *et al.*, 1998)** to work out the crop evapotranspiration (ET_c). The crop factor (k_c) of pearl millet during the summer season was 0.4, 1.05, and 1.15 after cutting, between cutting, and before cutting, respectively. While for fodder beet it was 0.75, 0.85, 1.1, and 0.75 at initial, developmental, middle, and maturity stages, respectively, (**Doorenbos and Pruitt, 1977)**.

Estimation of soil moisture content:

Measurements of soil moisture content (volumetrically) to follow the soil moisture of each crop at 3rd, 7th, 17th, and 25th irrigation events. Soil samples were collected according to **(James, 1988)**.

Table (6): average monthly reference evapotranspiration (ET_o) and rains under North Sinai conditions.

Month	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Rains*	5.30	0	0	0	0	0.70	4.70	8.30	13.30	11.70	9.70	8.30
ET_o	6	6.7	7.5	6.84	6.21	5.2	4.2	3.26	2.93	2.69	3.16	4.91

*Source: meteorological station in Baloza research station of Desert Research Center

Irrigation water is applied according to the methodology as described by **(Doorenbos and Pruitt, 1977).** The Amounts of irrigation water as leaching requirements (LR) were added permitting soil and water conditions at each site, (**James, 1988)**.

Estimation of drip lines uniformity:

Five micro-irrigation uniformity classifications, ranging from excellent to unacceptable, recognized by the American Society of Agricultural Engineers, (**ASAE, 1999)** were used to evaluate the drip irrigation system. The uniformity of dripper flow rates was calculated from the statistical distribution in terms of coefficient of variation (CV), distribution uniformity (DU), and statistical uniformity (SU) according to **(Evans *et al.*, 2007)**.

Irrigation water application efficiency (Ea%):

Water application efficiency (Ea%) were calculated for the 80 cm soil depth according to **(James, 1988)** as mean values of 3rd, 7th, 17h, and 25th irrigation events according to the equation:

$$Ea\% = ((W_s/W_f)*100)$$

where: Ea% = water application efficiency, (%); W_s= amount of water stored in the root zone, (m^3); and W_f= amount of water added to each plot, (m^3).

Water distribution uniformity (DU):

Water distribution uniformity (DU) is a ratio of the smallest accumulated depths in the distribution to the average depths of the whole distribution. A commonly used fraction in the lower quarter. The average accumulated water depth in the quarter of the field receiving the smallest depths is given by **(Burt *et al.*, 1997)**:

$$d_{lq} = \frac{volume\ acumulated\ in\ 25\%\ of\ total\ area\ of\ all\ elements\ with\ smallest\ depths}{total\ area\ of\ 25\%\ of\ the\ total\ area\ of\ elements}$$

d_{lq} = volume accumulated in 25% of the total area of all elements with the smallest depths divided by the total area of 25% of the total area of elements. From this, the low-quarter distribution uniformity, DU_{lq}, can be defined as:

$$DU_{lq} = \frac{d_{lq}}{d_{avg.}}$$

where: d_{avg} is the total volume accumulated in all elements or observations (m^3) divided by the total area of all the elements (m^2).

Crop yield:

Forage pearl millet yields were from three harvests (cuts) along the summer season. The first cut occurred 45 days after sowing (DAS), and a 35-day interval was left between each of the two following cuts up to the third cut (115 DAS). An area of 2.5 m^2 at each cut was harvested manually from each treatment. After recording the fresh weight of the total sample in the field, 2 kg was taken as a subsample were oven-dried at 70°C to constant weight for the estimation of dry matter content, and then the total dry matter was calculated for each treatment, which was then converted into tons per hectare.

Fodder beet at harvesting time (180 DAS) when plants showed signs of maturity which is indicated by leaf yellowing and partial drying of the lower leaves, three plants per replicate from the inner ridge were randomly hand-pulled to determine fresh and dry weights (g) of leaves and root. Fresh leaf and fresh root samples were dried in ovens at 70°C to constant weight for the estimation of dry matter content. The weighed mass of roots and leaves was converted into tons per hectare, (**Chakwizira *et al.*, 2014)**.

Water Use Efficiency (WUE):

Water use efficiency (WUE) was calculated according to **(James, 1988)** as the following equation:

$$IWUE = \frac{Y}{W_a}$$

where: IWUE = irrigation water use efficiency (kg m^{-3}); Y = total fresh or dry yield (kg ha^{-1}); and W_a = total applied water (m^3 ha^{-1}).

Energy applied efficiency (EAE) and energy requirements (ER):

One of the objectives of this study was devoted to quantifying the operating energy consumed by each drip irrigation system in considered sites. Another point that human energy was not taken into consideration in this study which the justification for this omission was that the human energy input into irrigation is relatively small, (**Kizer, 1976)**.

- **Power consumption use (B_P)** is calculated using the following formula according to (**Batty *et. al.*, 1975)**:

$$B_P = \frac{Q \text{ x } H_D \text{ x } Y_W}{E_i \text{ x } E_P \text{ x } 1000}$$

where, B_p = Power consumption use (kW); Q = total system discharge (m^3 h^{-1});"H_D = the total dynamic head of the system (m); Ei = the total system efficiency (%); Ep = pump efficiency (%); and Yw = water specific weight = 9810 N m^{-3}.

-The energy requirements (Er) (kW·h), was calculated according to the following equation:

$$Er = B_p \text{ x } T$$

where, B_p = power consumption use (kW); and T = irrigation time per season (h).

-Energy applied efficiency (EAE) was calculated as follows:

$$EAE = \frac{Y}{Er}$$

Where: EAE = energy applied efficiency (kg kW^{-1}); Er = Energy requirements (kW h)

Statistical Analysis:

The statistical design used was a randomized complete block design (RCBD) for one variable for each irrigation site alone. The obtained data were subjected to proper statistical analysis using Statistica Enterprise program v.10. The mean values were compared using the LSD test procedure at 5% level, **(Gomez and Gomez, 1984)**.

3. RESULTS AND DISCUSSIONS

Performance of the drip irrigation system:

Evaluation of the performance parameters of the installed irrigation system at the beginning of the experiment indicated that the coefficient of variation (CV) of flow rates was 0.052, which means a good performance of the D_I, according to **(Kirnak *et al.*, 2004)** which had concluded that a CV between 0.05 and 0.066 indicated a good performance of the drip system. Average values of statistical uniformity (SU) and distribution (DU) were 94.77% and 0.93, respectively. According to **(Smajstrla *et al.*, 1990)**, SU and DU greater than 90% and 0.87, respectively, imply an excellent functioning of the drip system. While the D_C found that a CV was between 0.035 and 0.045 indicated a poor performance of the irrigation system between considered sites, also the mean values of SU and DU were 84.4% and 0.73, respectively, that implies an inequitable functioning of conventional drip systems at considered sites of the selected villages.

Water application efficiency (Ea%):

Water application efficiency,(Ea%) presented in **Table (7)** as mean values obtained from different sites conditions through the two cultivated seasons by different treatments. In Dc during the summer season, the values of Ea% ranged from 81.2 to 84.8 %, while by D_IT_{75} it ranged from 97.3 to 99.2 %, however, D_IT_{100} was recorded midway between other treatments which were ranged from 93.5 to 95.6 %.

A similar trend of data results was obtained during the winter season, in which Dc the values of Ea% ranged from 82.2 to 83.8 %, while by D_IT_{75} it ranged from 97.5 to 98.3 %, however, D_IT_{100} was recorded midway between other treatments which ranged from 92.4 to 94.1 %. The water application efficiency was directly inversely proportional to the inflow discharge and the time of irrigation cutoff. It is entirely possible to irrigate with an application efficiency of 100% and still fail to grow a decent crop because Ea% does not consider the uniformity of the applied water in relation to the requirements of the crop, **(Pereira, 1999)**. However, the application efficiency is considered as the index of most revealing performance due to the high potential for water losses through deep percolation. Many soil and crop combinations require a certain volume of applied water to be drained from the bottom of the profile to prevent salt accumulation. Optimizing solely based on application efficiency will lead to a general reduction in deep percolation volumes which may decline below the leaching requirement, where leaching is important. It will impose an upper limit on the application efficiency, **(Smith *et al.*, 2011)**.

Table (7): Mean values of water application efficiency, Ea% from 3rd, 7th, 12th, and 25th irrigation events in summer and winter seasons

Site	Treatments	Summer 2015		Winter 2015/ 2016	
		Mean	SD*	Mean	SD
S1	D_C	81.208	1.018	82.213	1.835
	D_IT_{75}	97.263	1.276	97.745	0.959
	D_IT_{100}	93.497	0.941	92.997	0.924
S2	D_C	83.339	1.552	82.839	1.239
	D_IT_{75}	99.008	1.429	97.460	1.787
	D_IT_{100}	95.590	0.860	92.385	2.724
S3	D_C	82.829	1.294	83.079	1.743
	D_IT_{75}	99.172	1.113	98.163	1.280
	D_IT_{100}	95.088	1.084	93.588	0.875
S4	D_C	82.742	1.727	82.242	1.689
	D_IT_{75}	99.209	1.087	98.245	2.295
	D_IT_{100}	94.389	1.555	94.139	1.238
S5	D_C	83.528	2.326	83.778	2.564
	D_IT_{75}	99.084	1.071	98.058	2.436
	D_IT_{100}	94.921	0.835	93.421	2.564
S6	D_C	84.804	1.797	83.804	1.234
	D_IT_{75}	98.490	1.195	98.258	1.203
	D_IT_{100}	95.531	0.644	94.031	1.136

*SD = Standard division

Low-quarter distribution uniformity (DU_{lq}):

Concerning the low-quarter distribution uniformity (DU_{lq}), data in **Table (8)** illustrated similar trends for that the water application efficiency when using improved treatments for irrigated forage pearl millet and fodder beet crops under sites conditions. Values of DU_{lq}, with D_C during the summer season ranged from 0.67 to 0.69, while by D_IT_{75} it ranged from 0.91 to 0.94. However, D_IT_{100} was recorded midway between other treatments which were ranged from 0.88 to 0.91. A similar trend of results data was obtained during the winter season, in which D_c the values of DU_{lq} ranged from 0.68 to 0.69, while by D_IT_{75} it ranged from 0.9 to 0.92. However, D_IT_{100} was recorded midway between other treatments which were ranged from 0.89 to 0.91. Therefore, conducting a field evaluation of the DU of drip irrigation systems is often one of the very first steps in evaluating and improving on-farm irrigation efficiency, **(Burt *et al.*, 1997)**.

Table (8): Average values of water distribution uniformity of the low-quarter, DU_{lq} from 3rd, 7th, 12th, and 25th irrigation events in summer and winter seasons.

Site	Treatments	Summer 2015		Winter 2015/ 2016	
		Mean	**SD***	**Mean**	**SD**
S1	D_C	0.694	0.005	0.687	0.017
	D_IT_{75}	0.930	0.016	0.917	0.007
	D_IT_{100}	0.907	0.010	0.904	0.006
S2	D_C	0.684	0.010	0.678	0.008
	D_IT_{75}	0.937	0.010	0.921	0.019
	D_IT_{100}	0.898	0.012	0.908	0.015
S3	D_C	0.687	0.008	0.689	0.012
	D_IT_{75}	0.933	0.020	0.925	0.017
	D_IT_{100}	0.899	0.006	0.911	0.021
S4	D_C	0.686	0.004	0.686	0.018
	D_IT_{75}	0.912	0.013	0.908	0.011
	D_IT_{100}	0.891	0.005	0.895	0.012
S5	D_C	0.667	0.006	0.691	0.014
	D_IT_{75}	0.930	0.015	0.901	0.005
	D_IT_{100}	0.882	0.007	0.888	0.004
S6	D_C	0.694	0.011	0.678	0.012
	D_IT_{75}	0.926	0.013	0.903	0.011
	D_IT_{100}	0.901	0.008	0.890	0.013

*SD = Standard division

Crop yield:

Data in **Table (9)** presents the mean total of forage pearl millet fresh yield from three cuts seasonally (t ha^{-1}) affected by irrigation regime in the summer season at considered sites. The results indicated that the mean total of fresh yields was affected by irrigation treatments ($P = 0.05$) in all sites and it was significant differences with D_IT_{100} treatments compared with other irrigation treatments in all sites, while it was non-significant differences between D_IT_{100} and D_IT_{75} treatments in S2, and S5. D_IT_{100} treatments resulted in the highest mean values of total forage pearl millet fresh yields ranged from 81.9 to 104.1 t ha^{-1}, while D_IT_{75} treatments ranged from 71.6 to 100.5 t ha^{-1}. Remarkably, the study resulted in significant differences in fresh yields for total forage pearl millet irrigated at 75% ET_c under D_IT_{75} compared with D_C practices in all sites except in S3 and S6 with averages ranging from 69.9 to 89.9 t ha^{-1} by D_C as a control treatment under sites conditions, data proves that the local farmers cultivated the crop under sites conditions at a deficit level more than 75% ET_c. So, estimation of the crop water requirements and salts leaching requirements are still more important factors for enhancement fodder yield when irrigated crops under climate changes and salty environmental conditions, (**Hoffman, 1986).**

Data presented in **Table (9)**, also indicated that the mean values of total dry yields were affected by irrigation treatments (P = 0.05) in all sites and it was non-significant differences compared with D_IT_{75} treatments in sites S2, S4, S5, and S6. The D_IT_{100} treatments resulted in the highest mean values of mean total dry yields ranged from 19.6 to 28.8 t ha^{-1}, while compared to the D_IT_{75} treatments it ranged from 19.4 to 26.5 t ha^{-1}. It is noteworthy that the study resulted were significant differences between D_IT_{75} and D_C practices in all sites, except with the S3 site, averages ranged from 14.0 to 22.2 t ha^{-1} by D_C as a control treatment under sites conditions.

Data in **Table (10)** showed the mean total fodder beet fresh yield (t ha^{-1}) as affected by irrigation regime in the winter season at considered sites. The results indicated that fresh yields were affected by irrigation treatments (P = 0.05) in all sites and it was significant differences with D_IT_{100} treatments compared with other irrigation treatments in all sites, while it was non-significant differences between D_C and D_IT_{75} treatments in S2, S4, and S5.

The D_IT_{100} treatments resulted in the highest mean values of fresh yields ranged from 73.2 to 115.8 t ha^{-1}, while compared to the D_IT_{75} treatments it ranged from 82.9 to 98.1 t ha^{-1}. It is noteworthy that the study resulted in similar mean total fresh yields for fodder beets irrigated at 75% ET_c under D_IT_{75} or D_c practices, with averages ranging from 80.7 to 96.1 t ha^{-1} by D_c as a control treatment under sites conditions, it proves that the local farmers cultivated the crop under sites conditions at a deficit level less than 75% ET_c of crop water requirements. So, estimation of the crop water requirements is still a more important factor for good yield from irrigated crops under climate changes, **(El-Ramady *et al.*, 2013)**.

In the case of dry yield, data presented in **Table (10)** were the same trend of the results indicated that mean total dry yields were affected by irrigation treatments (P = 0.05) in all sites and it was significant differences with D_IT_{100} treatments compared with other irrigation treatments in all sites, while it was non-significant differences between D_C and D_IT_{75} treatments in all sites except S1 it was significant differences. The D_IT_{100} treatments resulted in the highest mean values of total dry yields ranged from 24.8 to 27.7 t ha^{-1}, while compared to the D_IT_{75} treatments it ranged from 23.2 to 24.5 t ha^{-1}. It is noteworthy that the study resulted in similar mean total dry yields for fodder beets irrigated at 75% ET_c under D_IT_{75} or D_c practices, with averages ranged from 22.3 to 23.7 t ha^{-1} obtained by D_c as a control treatment under sites conditions.

Applied irrigation amounts and water saving:

The most appropriate irrigation management concerns should satisfy both requirements of high yields and high water productivity “CWP”, (**Pereira *et al.*, 2012)**. In this regard, **Table (11)** showed the average water used for considered sites for each treatment along the two growing seasons**.**

Table (9): Effect of treatments on mean values of the fresh and dry yield of forage pearl millet (sum of three cuts) at considered sites.

Site		S1		S2		S3		S4		S5		S6	
	Treats.	Mean	SD*	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total fresh yield (t ha^{-1})	D_C	79.17 ^{c}	6.07	79.70 ^{b}	5.60	89.91 ^{b}	1.80	86.81 ^{c}	0.38	71.67 ^{b}	1.36	69.89 ^{b}	1.35
	D_IT_{75}	93.26 ^{b}	0.72	100.45 ^{a}	0.95	89.85 ^{b}	1.34	91.30 ^{b}	2.27	80.09 ^{a}	5.13	71.59 ^{b}	2.14
	D_IT_{100}	104.09 ^{a}	2.36	104.14 ^{a}	3.57	97.53 ^{a}	2.20	94.59 ^{a}	1.61	85.67 ^{a}	3.76	81.94 ^{a}	1.31
LSD P = 0.05		1.892		1.937		0.906		0.812		1.877		0.821	
Total dry yield (t ha^{-1})	D_C	21.35 ^{c}	1.86	22.22 ^{b}	1.88	22.00 ^{b}	0.59	18.80 ^{b}	0.39	16.49 ^{b}	0.39	14.04 ^{a}	1.02
	D_IT_{75}	25.30 ^{b}	0.21	26.50 ^{a}	0.25	21.56 ^{b}	0.32	20.41 ^{a}	1.24	19.43 ^{a}	1.24	19.57 ^{a}	0.98
	D_IT_{100}	28.81 ^{a}	0.35	28.07 ^{a}	1.33	23.52 ^{a}	0.29	20.34 ^{a}	0.53	20.31 ^{a}	0.53	19.61 ^{b}	1.12
LSD P = 0.05		0.551		0.669		0.213		0.1845		0.407		0.520	

Table (10): Effect of treatments on mean values of total fresh and dry yield of fodder beet at considered sites

Site		S1		S2		S3		S4		S5		S6	
	Treats.	Mean	SD*	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total fresh yield (t ha^{-1})	D_C	95.01 ^{c}	1.71	96.06 ^{b}	1.35	93.91 ^{c}	0.86	85.76 ^{b}	1.54	83.31 ^{b}	0.61	80.70 ^{c}	0.71
	D_IT_{75}	98.06 ^{b}	1.54	97.78 ^{b}	0.53	97.50 ^{b}	0.74	84.69 ^{b}	1.78	82.93 ^{b}	1.22	84.02 ^{b}	0.71
	D_IT_{100}	107.10 ^{a}	1.95	104.73 ^{a}	1.20	115.84 ^{a}	0.33	99.47 ^{a}	0.78	97.04 ^{a}	0.12	101.99 ^{a}	3.30
LSD P = 0.05		2.7913		1.74		1.087		2.294		1.263		3.186	
Total dry yield (t ha^{-1})	D_C	22.92 ^{c}	0.44	23.66 ^{b}	0.64	22.95 ^{b}	0.59	23.53 ^{b}	0.81	23.44 ^{b}	0.48	22.25 ^{b}	1.09
	D_IT_{75}	24.46 ^{b}	0.76	24.40 ^{ab}	0.44	23.83 ^{b}	1.23	23.15 ^{b}	0.70	23.31 ^{b}	0.67	23.52 ^{b}	0.68
	D_IT_{100}	25.59 ^{a}	0.67	24.82 ^{a}	0.44	27.02 ^{a}	1.34	27.47 ^{a}	0.51	27.36 ^{a}	1.24	27.72 ^{a}	0.77
LSD P = 0.05		1.019		0.83		1.765		1.091		1.378		1.380	

*SD = Standard division

Means with the same letters are not statistically different at $p = 0.05$

Table (11): Mean values of irrigation water used by forage pearl millet and fodder beet irrigated under treatments in considered sites conditions.

Site	forage pearl millet, **2015**			fodder beet, **2015/ 2016**		
	D_C	D_IT_{75}	D_IT_{100}	D_C	D_IT_{75}	D_IT_{100}
S1	5183	3586	4499	4739	3202	4357
S2	5006	3444	4373	4777	3144	4357
S3	5186	3271	4439	4831	3494	4292
S4	5186	3271	4439	4901	3474	4314
S5	5119	3187	4411	4828	3455	4335
S6	4994	3322	4272	4740	3474	4335
Mean	5112	3347	4405	4802.7	3373.8	4331.7
SD*	90.701	144.498	77.449	62.854	157.127	25.264

*SD = Standard division

Concerning the effect of treatments on mean values of irrigation water saving percentages are shown in **Fig. (2)** which resulted by comparing with D_c treatment, where, the average applied water amounts in considered sites conditions and illustrated previously in **Table (11).**

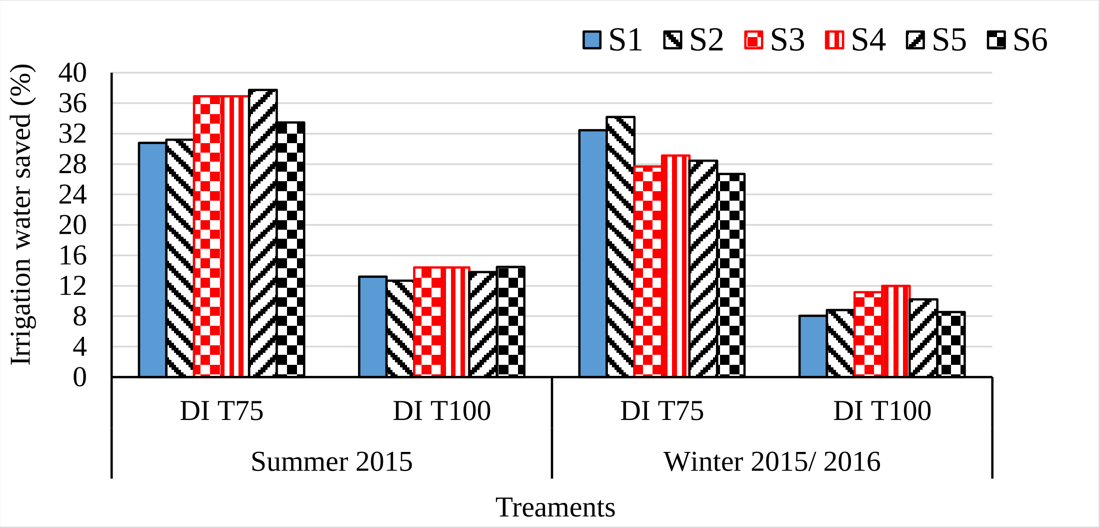

Fig. (2): Mean values of irrigation water saved by applying developing drip design and management under treatments at sites conditions.

Irrigation water use efficiency by both fresh yield ($IWUE_f$) and dry yield ($IWUE_d$):

The mentioned results in **Table (12)**, insuring that both redesigns of drip systems and water management have a good effect on the components of the water balance, thereby changing the proportion of plant water uptake (transpiration) in relation to losses. Using the proper amount of irrigation water and its application with site specific irrigation method can ensure reasonable gains in water use efficiency **(Pereira *et al.*, 2012 and Raza *et al.*, 2012)**.

Table (12): Mean values of Irrigation water use efficiency (IWUEf and IWUEd) by forage pearl millet and fodder beet irrigated under treatments in considered sites conditions.

Site	IWUE$_f$ (k g m^{-3})			IWUE$_d$ (k g m^{-3})		
	D$_C$	D$_I$T$_{75}$	D$_I$T$_{100}$	D$_C$	D$_I$T$_{75}$	D$_I$T$_{100}$
Forage pearl millet						
S1	15.28	26.00	23.14	4.12	7.06	6.40
S2	15.92	29.17	23.81	4.44	7.69	6.42
S3	17.88	25.09	22.35	4.37	6.02	5.39
S4	16.74	27.91	21.31	3.62	6.24	4.58
S5	14.00	25.13	19.42	3.22	6.10	4.60
S6	14.00	21.55	19.18	2.81	5.89	4.59
Mean	15.64	25.81	21.54	3.77	6.50	5.33
SD*	1.538	2.641	1.923	0.660	0.717	0.892
Fodder beet						
S1	20.05	30.62	24.58	4.84	7.64	5.87
S2	20.11	31.10	24.04	4.95	7.76	5.70
S3	19.44	27.90	26.99	4.75	6.82	6.30
S4	17.50	24.38	23.06	4.80	6.66	6.37
S5	17.26	24.00	22.39	4.86	6.75	6.31
S6	17.03	24.19	23.53	4.70	6.77	6.39
Mean	18.56	27.03	24.10	4.82	7.07	6.16
SD	1.454	3.302	1.609	0.089	0.494	0.296

*SD = Standard division

Operating energy consumption:

The consumed operating energy mainly depends on the amount of applied water and operating time. The consumed operating energy increased by increasing the water application rate from 75% to 100% of ET_c. Also, it increased by adding more tools to controlling and adjusting the water amounts by the developed systems due to raising the total dynamic head with adding more tools. The mean values of consumed operating energy are presented in **Table (13)** for seasons by irrigated both forage pearl millet and fodder beet under treatments in considered sites conditions.

Table (13): Mean values of consumed operating energy by irrigated forage pearl millet and fodder beet under treatments in considered sites conditions.

Site	Forage pearl millet			Fodder beet		
			(kW ha^{-1} season)			
	D$_C$	D$_I$T$_{75}$	D$_I$T$_{100}$	D$_C$	D$_I$T$_{75}$	D$_I$T$_{100}$
S1	1160.1	807.4	962.7	1200.6	749.0	993.3
S2	1193.7	945.9	1052.1	1231.7	783.4	1063.8
S3	1254.9	836.8	911.9	1330.3	858.5	957.8
S4	1290.1	742.8	908.0	1376.0	853.5	951.9
S5	1264.6	749.9	999.7	1285.6	914.6	1029.8
S6	1110.2	762.5	924.6	1367.1	865.1	959.2
Mean	1212.3	807.5	959.8	1298.6	837.4	992.6
SD*	69.420	76.852	57.176	72.028	60.239	45.712

*SD = Standard division

Concerning the effect of treatments on mean values of operating energy saved percentages are shown in **Fig. (3)** which resulted by comparing with D_c treatment, where the average consumed operating energy in considered sites conditions and illustrated previously in **Table (13)**.

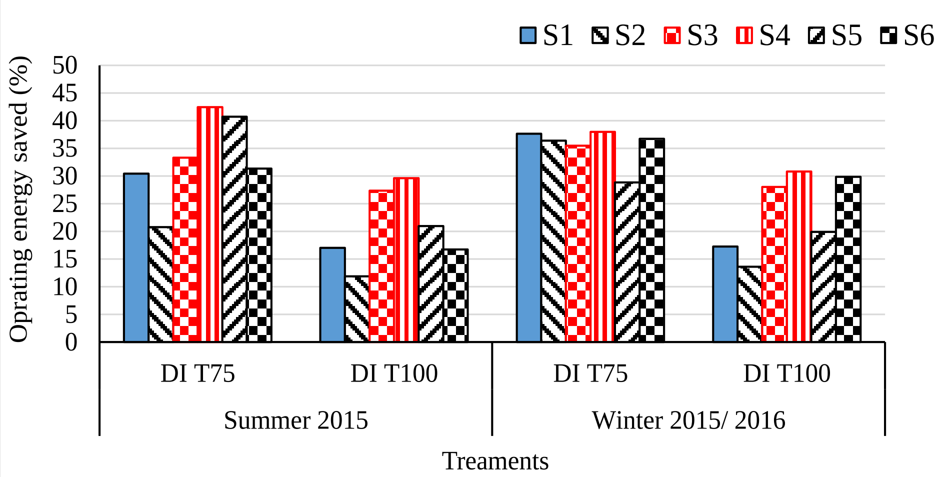

Fig. (3): Mean values of operating energy saved by applying development drip design and management under treatments of sites conditions.

Irrigation energy applied efficiency by both fresh yield (EAE_f) and dry yield (EAE_d):

The mean values of energy application efficiency were decreased by increasing the water application rate from 75% to 100% of ET_c. The mean values of irrigation operating energy applied efficiency are presented in **Table (14)** for irrigated seasons by both forage pearl millet and fodder beet under treatments in considered sites conditions.

Table (14): Mean values of irrigation energy applied efficiency (EAE_f and EAE_d) by forage pearl millet and fodder beet under treatments in considered sites conditions.

Site	**EAE_f (kg kW^{-1})**			**EAE_d (kg kW^{-1})**		
	D_C	**D_IT_{75}**	**D_IT_{100}**	**D_C**	**D_IT_{75}**	**D_IT_{100}**
			Forage pearl millet			
S1	68.24	115.51	108.13	17.78	33.78	29.01
S2	66.77	106.20	98.98	18.04	33.83	26.39
S3	71.65	107.38	106.96	16.54	25.12	24.55
S4	67.29	122.91	104.17	13.66	23.92	21.37
S5	56.67	106.80	85.69	12.83	21.24	19.72
S6	62.96	93.89	88.62	10.27	22.62	20.45
Mean	65.60	108.78	98.76	14.85	26.75	23.58
SD*	5.186	9.789	9.570	3.104	5.614	3.685
			Fodder beet			
S1	81.90	121.45	111.26	19.09	32.65	25.76
S2	80.47	103.37	99.54	19.21	31.15	23.33
S3	74.83	116.52	127.04	17.25	27.76	28.21
S4	66.47	114.01	109.55	17.10	27.13	28.86
S5	65.88	110.60	97.07	18.24	25.48	26.56
S6	72.69	110.20	110.30	16.28	27.18	28.90
Mean	73.71	112.69	109.13	17.86	28.56	26.94
SD	6.763	6.174	10.624	1.176	2.738	2.179

*SD = Standard division

4. SUMMARY AND CONCLUSION

It can be concluded that implementation of a modified drip irrigation system and management will be led to saving the water, operating energy, and consequently increase the irrigated areas by about 25-30% approximately. In conclusion, modify the drip irrigation system by applying improved management and good tools under soil and water conditions of North Sinai will lead to an increase in the productivity of forage yields, water-saving, and irrigation energy applied efficiency, and consequently improve the farmer's income. In addition, applying the adjusted drip irrigation system under North Sinai conditions is necessary, because of its marginal conditions, high energy unit cost, and water shortage.

Design development requires capital in adding equipment. Moreover, scientific irrigation scheduling represents a fundamental change in the traditional grower attitude toward water management and saving. Realistically, this change will occur only by economic returns can be normally derived from scientific irrigation system design and management.

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تحديث أنظمة الري بالتنقيط لتحسين إنتاج محاصيل العلف وترشيد المياه الجوفية في شمال سيناء - مصر: دراسة حالة

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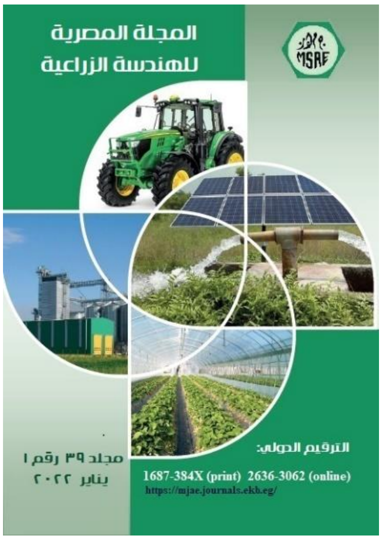

الملخص العربي

أجريت تجارب حقلية في قريتي رومانة وبئر العبد بمحافظة شمال سيناء في ثلاثة مواقع لكل منها، تمت زراعتها بمحاصيل علف الدخن اللؤلؤي وبنجر العلف خلال صيف ٢٠١٥ وشتاء ٢٠١٦/٢٠١٥ على التوالي. وذلك لتقييم أثر تحديث نظام الري بالتنقيط (D_I) مع استخدام مستويين من تطبيقات مياه الري: ١٠٠ و٧٥٪ من متطلبات المياه الفعلية للمحاصيل (ET_c) كمعاملات T_{100} وT_{75}، على التوالي، والمقارنة مع أشكال أنظمة الري بالتنقيط التي يستخدمها المزارعون المحليون للري (D_C). مقاييس الأداء كانت: التوزيع الإحصائي لمعدلات تصرف النقاطات، وكفاءة استخدام مياه الري "Ea٪"، وانتظام توزيع للربع الأدنى "DUlq"، والمحصول الطازج والجاف في كل موسم، وكفاءة استخدام المياه لكلا من المحصول الطازج "WUE_f"، والجاف "$WUEE_d$"، وكفاءة استخدام الطاقة في كلا من المحصول الطازج "EUE_f"، والجاف "EUE_d". كانت أهم النتائج المتحصل عليها هي:

كان هناك أداء جيد مع (D_I) من خلال الأداء الممتاز للتوزيع الإحصائي لمعدلات تصرف النقاطات. وتم تسجيل أعلى متوسط لقيم (Ea٪)، و(DUlq)، و($IWUE_f$)، و($IWUE_d$)، و(EAE_f)، و(EAE_d) بواسطة معاملات D_IT_{75} في كلا الموسمين، لجميع المواقع. كما سجل إجمالي المحصول الطازج والجاف بمعاملات D_IT_{100} أعلى متوسط للقيم في كلا الموسمين لجميع المواقع. وكانت متوسطات القيم لنسب توفير المياه من ٣٤,٥ الى ٢٩,٨٪ بمعاملات D_IT_{75} ومن ١٣,٨ الى ٩,٨٪ بمعاملات D_IT_{100} تم الحصول عليها في موسمي الصيف والشتاء على التوالي، بالمقارنة مع المعاملة (D_C) بين جميع المواقع. بينما كانت متوسطات القيم لنسب توفير الطاقة التشغيلية للري من ٣٣,٢ الى ٣٥,٥٪ بمعاملات D_IT_{75} ومن ٢٠,٦ الى ٢٣,٢٪ بمعاملات D_IT_{100} في موسمي الصيف والشتاء على التوالي.

الكلمات المفتاحية:
الري بالتنقيط؛ إنتاج محاصيل العلف؛ ترشيد المياه الجوفية والطاقة التشغيلية للري.