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Design Criteria of Permanent Sprinkler Irrigation System to Maximizing Water Productivity under Marginal Conditions

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ABSTRACT

Field experiments were conducted at El-Tina Plain, North Sinai governorate, Egypt, in growing seasons of 2012, 2013 and 2014 to evaluate of design criteria of permanent sprinkler irrigation “PS” under marginal conditions using impact sprinklers with different nozzle diameter and different operating pressure. The other purpose is the response of forage millet yield to seasonal applied water depth and to maximizing the water productivity.Christiansen uniformity coefficient values by different range levels “CUc”, irrigation water use efficiency “IWUE”, water lost by percolation “DP” and irrigation adequacy “pa” was estimated through field experiments. The randomized complete block design with four replications was used. Experimental treatments consisted of five different sprinkler irrigation uniformity range levels: "CUc1" (90 -95%), "CUc2" (80 - 85%),"CUc3" (70 - 75%), "CUc4" (60 - 65%) and "CUc5" (50 - 55%).The obtained results showed that the maximum value of irrigation adequacy was 69% for CUc1 treatment, while its minimum value (38.8%) was obtained for CUc5 treatment. By increasing irrigation uniformity coefficient, the irrigation adequacy increased, while the water losses decreased. The maximum value of water losses “Dp” was 26.15% for CUc5 treatment, while the minimum value was 7% for CUc1 treatment. By decreasing the irrigation uniformity coefficient "CUc" the high losses of irrigation water "Dp" was caused. Forage millet yield depends on both the application depth of water and the sprinkler irrigation performance, but it is more sensitive to the differences in applied water depth than to the differences in sprinkler irrigation uniformity. Therefore, the good uniformity of the irrigation system under marginal conditions does not mean high forage yield. The methodology of this study could have useful applications in design optimization, management and promotion of permanent sprinkler irrigation system and in deficit irrigation planning under marginal conditions, such as El-Tina Plain.

Keywords*:* Permanent sprinkler irrigation*,* Uniformity Coefficient, Water adequacy, forage millet, water use efficiency, North Sinai.

INTRODUCTION

One of the main challenges of the world is water and food security. The increasing food request and declining water allocation propose that the agricultural sector has to maximize agricultural water productivity for making more food with less water (Cai and Sharma 2010). In the marginal areas, agriculture is not beneficial or even impossible without irrigation. Therefore, any irrigation system should meet the objectives of production which will be achieved through the optimization of investment and running costs. A number of parameters have to be established to design the system. These parameters may be classified into ecological limitations and decision limitations. The ecological limitations cannot be modified and have to be taken into account as information for the system design. The latter depends on the designer choices, Lamaddalena and Sagardoy (2000). Available resources of water for irrigation is becoming more restricted around the world, and this trend is quickening mainly in Egypt. Developing computerized accuracy irrigation technologies will enable farmers to Huse water and agrochemicals quieter and site-specifically to match the conditions, Evans (2014). Irrigation managing and irrigation systems improvement have a highly important part of water productivity, Khadra and Lamaddalena (2006). For sprinkler system, it is also of interest to analyze the energy concert of the irrigation system and crop yield (e.g., energy output to input ratio, i.e., crop energy created per unit of energy used in systems production, or crop energy made per unit water used, MJ m^{-3}) (Rodrigues *et al.*, 2010 and Rodríguez *et al.*, 2012).

Design criteria for the water use configuration from a line sprinkler plot irrigation system are defined by Hanks *et al.* (1976) to obtain the best spacing of line sprinkler is necessary to combine between 1) Uniformity along the plot which is optimum with sprinklers spaced at approximately 10% of the wetted diameter and realistic for spacing’s around 20-25% of the wetted span. 2) The flow rate and system rate of applied which varies upon the sprinkler spacing. 3) Increases the system cost which the sprinkler spacing is decreased. As application rate and costs are necessary to use the widest layout which will give acceptable uniformity, i.e., differences along the line not more than ± 10% of the average. The irrigation uniformity is an important indicator of the performance of sprinkler irrigation systems. So, it must be considered throughout design and installation of the system, which it was more sensitive to the operating pressure combination, nozzle diameter and height of risers (Wenting and Pute, 2011 and Osman *et al.*, 2014). Water distribution pattern resulted from sprinkler type, nozzle type, speed rotation, crop meddling, faulty sprinkler heads, and non-vertical risers (Playa and Mateos 2006, Kassem 2009 and Hanson *et al.*, 2011). Also, Zhang *et al.* (2013) reported that the differences in the DU can reduce by 10 to 20%, depending on nozzle spacing and field size. Christiansen Uniformity Coefficient “CUc” calculated according to Christiansen (1941) it is a usually used as a performance indicator in sprinkler uniformity assessment. Low CUc values often indicate an improper combination of nozzle number and size, operating pressure, and sprinkler spacing (Tarjuelo *et al.* 1992).

Many papers have been written about the factors affecting on sprinkler application uniformity such wind velocity, spray nozzles, water runoff, and soil erosion, Mateos *et al.* (1997), Jiusheng and Kawano (1996), Mantovani *et al.* (1995), and Kranz and Eisenhauer (1990).

Daccache *et al.* (2010) concluded that a methodology for simulating the interaction between on-demand water distribution systems and on-farm irrigation networks has been defined and used on a case study to assess the implication of pressure variation on the irrigation performance.

The development technique of any irrigation system follows a systematic sequential order: design, construction, and management, Daccache *et al.* (2010). So, a number of software applications prepared to evaluate the hydraulics of pressurized irrigation systems for the analysis of design situations under different operating conditions in terms of water application uniformity and other design criteria, Pinthong *et al.* (2013). Lamm and Rogers (2015) concluded that extensive water savings are possible when ET-based irrigation scheduling is implemented for marginal capacity irrigation systems. Xue and Ren (2016) stated that the performance of the SWAP-WOFOST model was adequate for model validation, relation to crop yield, ET, water table depth, and drainage efficiency. The simulated results showed that the irrigation amounts in the sprinkler irrigation scenario for spring wheat, spring maize, and sunflower were 45.8%, 0.8%, and 41.8%, respectively, lower than that for the basic scenario.

Wang *et al.* (2015) assessed and calibrated the modified HYDRUS-1D model and validated by using data collected from two winter wheat growing seasons. The predicted values for soil moisture content, soil nitrate concentration, crop progress, yield, and evapotranspiration showed good promises with the measured values. The calibrated model was then used to assess the yield and irrigation water use efficiency (IWUE) . Different described of mathematical models for the hydraulic alternatives of a field-scale solid set sprinkler irrigation system (Singh, 2014 and Zerihun and Sanchez, 2014) in integration between simulation and optimization models revealed that the optimal conjunctive between water management scenarios may not be attained by separate uses of simulation or optimization models.

In many studies, concerning the water productivity (WP) has introduced as a more inclusive index for evaluation of water management and study of water use efficiency in agriculture (Kijne *et al.*, 2003; and Wichelns, 2002). Rodrigues and Pereira (2009) reported that particularly for small farms where perfect management may not be possible or economically feasible. This implies that in addition to WP, economic water productivity (EWP) should also be considered. The EWP for various scenarios of irrigation was influenced by the water and energy costs. The particular attention to the enhancement of irrigation management showed much better economic return than the improvement of the irrigation components. Therefore, the modernization of the irrigation systems offers for the farmers a mostly options to expand his economic output of water use, Playa and Mateos (2006).

In this study, the received water in various parts of the field and irrigation adequacy were calculated to evaluate the effect of these indices on crop yield and estimated water productivity based on water-yield of forage millet functions in Al-Tyna Plain region, North Sinai along three successive seasons.

MATERIALS AND METHODS

Location and soil of experimental field:

Field experiments were conducted at El-Tina Plain, North Sinai governorate, Egypt, in growing summer seasons of 2012, 2013 and 2014 to investigate the effect of the uniformity coefficient and adequacy effects on crop yield and crop water productivity (WP) under saline environment conditions. The randomized complete block design with four replications was used. The irrigation system was permanent sprinkler irrigation (PS), the geographical location of the farm is sited at 30° 54' 45.37" N and 32° 23' 35.22" E, (Table 1) showed the soil type of this farm is classified as a loamy sand soil along 30 cm depth were measured according to Klute (1986), the bulk density was 1.61g cm-3 and low organic matter 0.18 %. Soil porosity (St) was calculated using the formula: St% = 100 (1-Db Dp^{-1}).

Some chemical properties were determined according to the methods described by Black (1965).

Table 1. Some properties for the experimental site before cultivation at El-Tina plain, Egypt

soil depth (cm)	Soil texture class*	Bulk density (g cm^{-3})	Porosity (S_t %)	Water table level (cm)	Saturated hydraulic conductivity(cm h^{-1})	Field Capacity (v%)	Wilting Point (v%)	Avalable water (v%)	Avg. Salinity of drainage water (dSm^{-1})	pH	EC (dS m^{-1})	ESP (%)	Organic matter (%)	Total nitrogen (%)	Available phosphorus (ppm)	Exchangeable potassium (meq.100g soil^{-1})
0 -30	LS	1.6	31.5	84	11.3	17	8.21	8.8	20.5	8.0	5.5	16.3	0.2	0.1	8.5	0.7
30-60	S	1.7	28.9	(80-92)						8.1	4.9	16.3	0.2	0.2	9.4	1.0

*** LS = Loamy sand, and S= Sand**

The irrigation water was obtained from El Salam Canal. The irrigation water has a pH of 7.07 in average and total soluble salts of 2.43 dS m^{-1} in average. Sodium adsorption ratio (SAR) value was 5.81 in average.

Table 2. Irrigation water properties.

Season	pH	EC (dS m^{-1})	Soluble Cations (mg L^{-1})				Soluble Anions (mg L^{-1})			SAR
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{--}	
2012	7.1	2.5	5.0	7.0	12.9	0.5	4.4	14.2	6.8	5.5
2013	7.0	2.2	4.0	5.5	12.1	0.7	2.9	14.2	5.1	5.5
2014	7.1	2.5	5.1	5.1	14.4	0.6	3.1	16.7	5.3	6.4

The field study included designing a permanent sprinkler irrigation system, which provided five different range levels (treatments) of Christiansen uniformity coefficient "CUc". They were 90- 95% (CUc1), 80- 85% (CUc2), 70-75% (CUc3), 60- 65% (CUc4) and 50-55% (CUc5). These levels of uniformity coefficient were obtained by using impact sprinklers with different nozzle diameter and different operating pressure. The experimental design was randomized complete block. Each treatment contained four replicates. Each plot had one flow meter, one pressure regulator and pressure gauge to control the operating pressure and measure the quantity of applied irrigation water. A buffer zone of 2 m separated between treatments to avoid interference .

Catch cans of 120 mm diameter and 200 mm height were used to collect irrigation water. Each 8 m × 8 m plot was divided into a grid of sixteen 2 m × 2 m subplots. Sixteen catch cans were placed at the center of each subplot 70 cm above the soil surface, and no surface runoff was found in the experiments.

Sprinkler water uniformity the coefficient tests as well as applied and collected irrigation water depths were performed at each plot during the irrigation season (three irrigation tests events seasonally). The experiments were carried out before and during the millet growth. One before millet grown and two during millet growth. Those sprinkler evaluations were done according to the methodology of Merriam and Keller (1978) and Merriam *et al.* (1983). The duration of each evaluated event was determined on bases that the water collected depth resulting from the overlapping of wetted diameters is equivalent to the irrigation depth required for each irrigation event Allen *et al.* (1998).

Irrigations were performed when the calculated soil water balance reached 60% of the total available water within top 30 cm layer for the first month, then within top 60 cm after this month. (About 24.5 and 48.9 mm depletion for the first month and for next days, respectively). Each irrigation event lasted for the time required to regain field capacity .

Forage millet water requirement (ETo) was estimated using the Penman-Monteith formula (Smith, 1992). The crop coefficient of forage millet adopted during the crop season were 0.55 (0; 20 days after grown or cuts) - 0.65 (21; 40 days) - 1.05 (41; 45 days or until cutting) 4 cuts during each season.

To evaluated agronomic characters and water productivity, samples of the crop were taken each cut to yield estimations from (1m X 1m) central area of each subplot. The mean values of forage yield were determined for each plot .

Irrigation efficiency equations and Indices:

Irrigation efficiency in sprinkler irrigation is defined by Burt *et al.* (1997) altered and refined this original definition. Now technical irrigation efficiency (or classical irrigation efficiency) is commonly defined as the fraction of the applied water that is beneficially used. From the irrigation engineering perspective this ‘beneficial use’ is applying water to the root zone of the crop. Irrigation engineers distinguish between conveyance (Ec), distribution (Ed) and application (Ea) efficiencies.

Keller and Bliesner, (1990) defined the irrigation efficiency in sprinkler irrigation as:

$$E_{pa} = DE_{pa}\, R_e\, O_e \quad \text{-------------------------- (1)}$$

Where, **pa: irrigation adequacy (%), Oe: the ratio of received water to the entered water to the system, Epa: application efficiency in pa (%), Re: the effective fraction of irrigation water (it is evidence for drift and evaporation losses during the irrigation event). DEpa: Distribution Efficiency in various pa and CU values (Keller and Bliesner 1990):**

Christiansen uniformity coefficient (CUc) values for forage yield and water use efficiency of forage millet were determined to depend on subplots data. CUc, the percentage of water losses by evaporation "EL" and percentage of water losses by deep percolation "Dp". The standard deviation describing the shape of the distribution is defined by the irrigation uniformity coefficient (CU) for a given irrigation application system, Zhu *et al.* (2012). Receiving irrigation water at any point in the field could be calculated from most commonly used the term is Christiansen’s coefficient of uniformity (Christiansen, 1941) expressed in Eq. (2) as a percent :

$$CU = \left[1 - \frac{\sum_{i=1}^{n} |h_i - \bar{h}|}{n\bar{h}}\right] \times 100 \quad \text{--- (2)}$$

Where: **hi = water depth collected in catch cans; ‾h = mean water depth collected in all catch cans; and n = total number of catch cans used in the evaluation.**

$$EL = \frac{Aw - Cw}{Aw} * 100 \quad \text{--- (3)}$$

$$Dp = \frac{Cw - Sw}{Cw} * \quad \text{----- (4)}$$

Where:-

EL= Percentage of water losses by evaporation, %;
Aw= Applied water depth, mm;
Cw= Collected water depth, mm;
Sw = water needed to regain field capacity in root zone, mm;

Kruse (1978) defined application efficiency as:

***E*a = (average depth of water stored in the root zone) × 100 / (average depth applied) ------- (5)**

For in-field evaluations where the depth of water applied is less than the root zone moisture deficit prior to irrigation and runoff is not evident, the irrigation water available to the crop can be assumed to be equal to the average depth of water applied as measured at the soil surface (e.g., with catch cans in sprinkler system). In these cases,

***E*a = [average depth applied (mm) × area (ha)/10] × 100 / [water delivered to the field(m^3)]**

Irrigation Water Use Efficiency (IWUE)

The water use efficiency is more complex for irrigated agriculture because proper consideration must be given to the water received during the crop growing season and water stored in the root zone. Because the yield response to water is a curvilinear function (Wanjura *et al.*, 2000), the efficiency of irrigation water application depends on the amount and distribution of applied water. Irrigation water use efficiency is a measure of the water use efficiency that explains the crop yield response to irrigation (Bos, 1979; Howell, 2003). Irrigation water use efficiency can be expressed as Eq(6).

IWUE = Y (SAW)$^{-1}$ ----------------------- (6)

Where:

IWUE = Irrigation water use efficiency, kg m^{-3};
Y = the fresh forage yield, kg m^{-2};
SAw = the seasonal amount of applied water, m^{3} m^{-2}.

The numerator of this equation can be total aboveground biomass depending on the use of the crop production, and the denominator varies from crop evapotranspiration to soil water balance. In terms of the soil water balance and agronomic water use efficiency (Gregory, 2004).

The results were subjected to analysis of variance by F test, and the means were compared (ANOVA) and least significance differences (LSD) test was used for comparing at 0.05 level of probability according to Snedecor and Cochran(1982).

RESULTS AND DISCUSSION

Uniformity coefficient of irrigation water:

The values of measured irrigation uniformity for all irrigation tests at the range of irrigation uniformity design. The mean values of irrigation uniformity were 91.42, 81.76, 72.12, 62.50 and 53.3% for treatments CUc1, CUc2, CUc3, CUc4 and CUc5. Fig. (1) Shows the cumulative frequency of water distribution pattern for the five treatments of uniformity coefficient CUc1, CUc2, CUc3, CUc4, and CUc5 .

The adequacy of irrigation "percentage of the area received the mean depth of received water or more" and irrigation insufficient "percentage of the area received the depth of water less than mean depth of received water" were determined from the cumulative frequency of water distribution pattern, Fig.(1) .

For irrigated area had insufficient irrigation, the degree of water stress increased by decreasing the received water depth. Fig. (1) Indicated that the last 20% of the irrigated area (0.8 - 1.0 of the irrigated area) received the depth of water less than 0.55 of mean received water depth for treatment CUc5, while the corresponding area for treatment CUc1 received the depth of water less than 0.9 of mean received water depth. By increasing irrigation uniformity coefficient, the received water depth for last 20% of the irrigated area increased. From the above mentioned indicated that plants in this area for treatment CUc5 suffer from height water stress, while plants in the same area of treatment CUc1 did not suffer from any water stress.

The values of the adequacy of irrigation “pa” and irrigation insufficient are shown in Fig. (2) the data revealed that the maximum value of irrigation adequacy was 69% for treatment CUc1, while the minimum value was 38.8% for treatment CUc5. The maximum value of irrigation insufficient was 61.2% for treatment CUc5, while the minimum value was 31% for treatment CUc1. By increasing irrigation uniformity the irrigation adequacy increased while irrigation insufficient decreased.

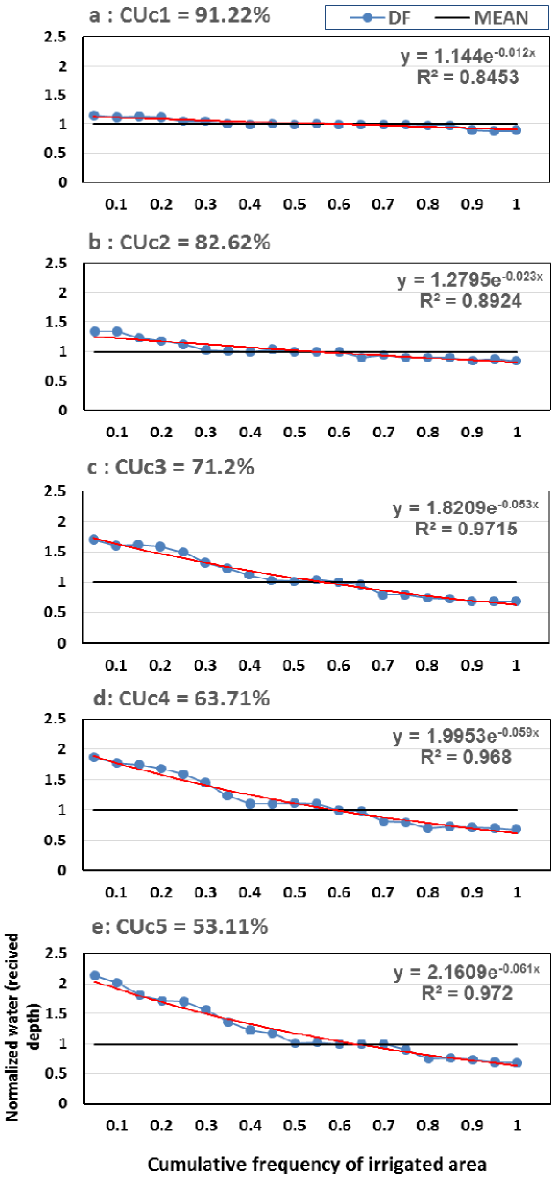

Fig. 1. Cumulative frequency of water distribution pattern for five levels of irrigation water uniformity.

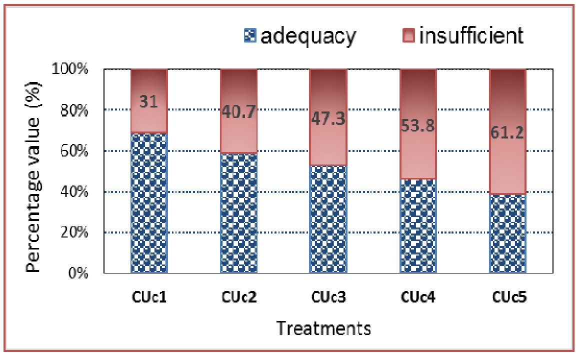

Fig. 2. Effect of irrigation uniformity on irrigation adequacy and insufficient adequacy of permanent sprinkler irrigation

Effect of irrigation uniformity coefficient on water losses by deep percolation:

Fig.(3) illustrates the percentage of water losses by deep percolation under 60 cm depth for the five treatments. The results indicated that irrigation uniformity coefficient had a highly significant effect on water losses by deep percolation (Dp).

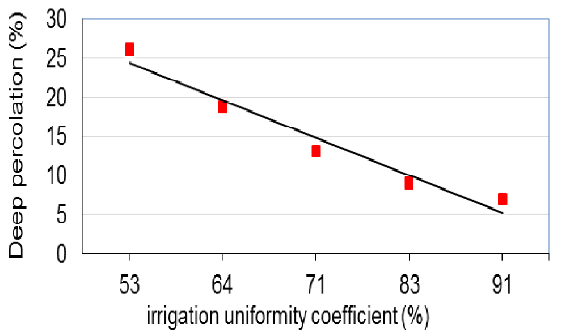

Fig. 3. Effect of irrigation uniformity coefficient on water losses by deep percolation

By decreasing, irrigation uniformity coefficient water losses by Dp increased. It reached a maximum value 26.15% for treatment CUc5, while the minimum value 7% obtained at treatment CUc1. By decreasing the irrigation uniformity coefficient, the depths of received water for some subplots were increased. Greater irrigation depth over 60.4 mm allowed water to move more than 60 cm beyond wheat root zone causing big water losses by Dp. So, decreasing the irrigation uniformity coefficient caused high percentage losses of irrigation water by Dp, while increasing irrigation uniformity coefficient reduced water losses and keep it within the reach of wheat root zone. The relationship between the percentage of water losses by Dp and irrigation uniformity coefficient was found to be a linear relation and obtained in equation (6).

$$\mathbf{Dp = (-4.809{*}CUc) + 29.251 \quad (R^2 = 0.9556) \text{ ------- } (6)}$$

By aligning irrigation water application with variable water requirements in the field, total water use may be reduced, decreasing deep percolation and surface runoff. Reducing excess water applications will decrease the potential to move nutrients past the plant root zone (Sadler *et al.* 2000 and 2005) .

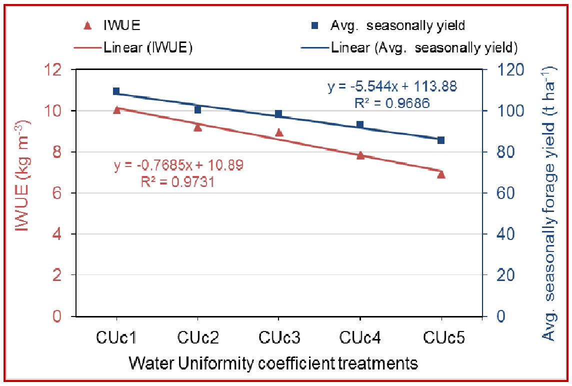

Fig. 4. Effect of uniformity coefficient on millet forage yield and IWUE.

To discuss variations in forage yield and water use efficiency as a function of the water distribution, the indices were determined for each of the 16 subplots in the main plots. Fig. (4) shows forage yield and water use efficiency as a function of seasonal received water depth. Two parameters were increasingly affected by the seasonal received water to 1086.8 mm depth. Forage production reached their maximum values 109.3 t ha^{-1}, the increments were 8.11, 10.07, 14.93 and 21.95% compared with CUc2, CUc3, CUc4, and CUc5, respectively. While the water use efficiency curve exhibits a negative correlation and the results indicate that a reduced seasonal water depth increases the water use efficiency of the crop. Water use efficiency reached its maximum value of 10.06 kg m^{-3}, the increments were 8.42, 11.22, 22.17 and 31.34% compared with CUc2, CUc3, CUc4, and CUc5, respectively.

By increasing the seasonal water depth crop height and forage yield increased, while water use efficiency decreased. Regarding the regression analysis, a quadratic relationship was observed between the parameters and the seasonal received water depth and shown in the Fig(4) .

Data presented in (Table 3) show the effect of irrigation uniformity coefficient on forage yield and water use efficiency. The mean values of these parameters were significantly increased by increasing irrigation uniformity coefficient. The treatments CUc1 and CUc2 recorded the highest values of forage yield and water use efficiency with significant differences with other treatments.

Table 3. Effect of irrigation uniformity coefficient on forage yield and irrigation water use efficiency (IWUE).

Parameters	**Water Uniformity treatments**				
	CUc1	**CUc2**	**CUc3**	**CUc4**	**CUc5**
Avg. seasonally fresh yield (t ha^{-1})	109.3a*	100.4a	98.3b	93.0c	85.3d
IWUE (kg m^{-3})	10.1a	9.2a	8.9b	7.8b	6.9c

*** the same letter in the same row are not statistically different at P<0.05 level**

Meanwhile, treatment CUc5 had the lowest values for all previous parameters. The treatments CUc1 had the highest values of forage yield and water use efficiency 109.3 t ha^{-1} and 10.06 kg m^{-3}, respectively, with insignificant differences with treatment CUc2, while the lowest values of forage yield and water use efficiency 85.3 t ha^{-1} and 6.9 kg m^{-3}, respectively .

Effect of Christiansen uniformity coefficients on forage millet yield and water use efficiency:

The Christiansen uniformity coefficients of forage millet yield and efficiency of water use as a function of irrigation performance. Analysis of the relationships reveals a greater reliance on water use and efficiency on irrigation performance compares to forage yield. Christiansen uniformity coefficients ranged from 52.11 to 91.22% for forage yield during the irrigation seasons, Fig. (4).

The results showed that the uniformity coefficient of the permanent sprinkler irrigation system has a significant effect on growing forage millet, forage yield, and efficiency of water use. However, high sprinkler irrigation performance does not routinely mean high forage yield. The yield depends on both the practical water depth and the sprinkler irrigation water uniformity but it is more sensitive to the variations in applied water depth than to the changes in sprinkler irrigation uniformity, a similar result reported by Li and Rao (2000) .

Water Productivity index for different values of uniformity coefficient and irrigation adequacy:

The results of this study after three seasons showed that in a given irrigation adequacy levels, water productivity reduces by decreasing uniformity coefficient. This reduction is more intensive at higher adequacy levels. Significant coupled effects of irrigation adequacy and uniformity coefficient on forage yield make notes that the uniformity coefficient index alone cannot be a good criterion in irrigation system evaluation Fig. (5). In addition, in the application of deficit irrigation strategies and treatments, irrigation adequacy will not be sufficient alone and considering uniformity coefficient is very important. Therefore, irrigation evaluation, planning, and deficit irrigation optimizing should consider coupled effects of irrigation adequacy and uniformity coefficient.

In irrigation system with lower uniformity, more irrigation adequacy will lead more discrepancy between over and under-irrigated areas of the field. This will lead to more difference between crop growth and yield in various parts of the field. Therefore, it can be concluded that in irrigation systems with lower uniformity, lower adequacy levels, as a deficit irrigation strategy, will be more justified, Nazari *et al.* (2013) reported a similar result .

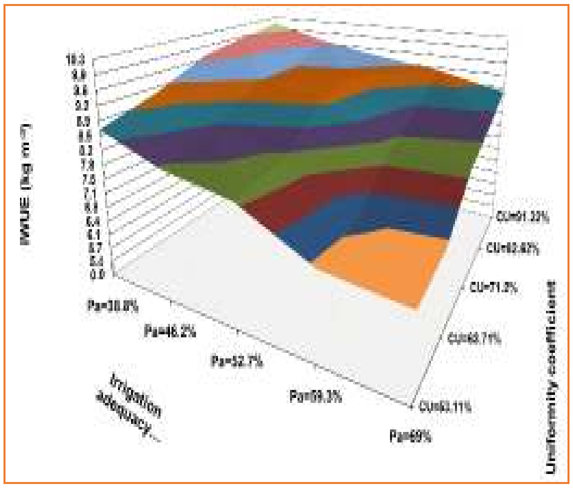

Fig. 5. Water Productivity index for different mean values of irrigation adequacy and water uniformity for forage millet crop along three seasons.

CONCLUSION

The purpose of this research work is to explore the effect of sprinkler irrigation uniformity coefficient on forage millet crop yield, water use efficiency, water losses by deep percolation and irrigation adequacy through field experiments. Also, to study its effect on Christiansen uniformity coefficient values of forage millet crop yield and water use efficiency. The other purpose is to obtain the response of forage millet crop yield to seasonal applied water depth. Treatments consisted of five different sprinkler irrigation uniformity values: "CUc1" (90 - 95%), "CUc2" (80 - 85%),"CUc3" (70 - 75%), "CUc4" (60 -65%) and "CUc5 "(50-55%).

The obtained results indicated that:

1. The maximum value of irrigation adequacy was 69% for treatment CUc1, while the minimum value was 38.8% for treatment CUc5. By increasing irrigation uniformity coefficient the irrigation adequacy increased while irrigation insufficient decreased.
2. The maximum value of water losses percentage by deep percolation was 26.15% for treatment CUc5, while the minimum value was 7% for treatment CUc1. By decreasing the irrigation uniformity coefficient "CUc" caused high losses of irrigation water by deep percolation "Dp". The relationship between "Dp" and "CUc" was found to be a linear relation: Dp = (-4.809*CUc) + 29.251
3. Through the seasonal water depth as a function of maximum average seasonal received water depth 1086.8mm, forage millet crop yield increased and reached to their maximum values 109.3 t ha-1. The water use efficiency increased by decreasing the seasonal water depth and reached to its maximum values 10.1 kg m-3
4. The treatments CUc1 had insignificant differences with treatment CUc2. While the lowest values of forage millet crop yield and water use efficiency 85.9 t ha-1 and 6.9 kg m-3, respectively for treatment CUc5.
5. when an irrigation depth is proposed as an optimum option for achieving maximum crop yield or maximum water productivity, this value should be proposed regarding irrigation adequacy and uniformity coefficient values. In this situation, I can expect that more area of the field had received optimum or near optimum irrigation amount. Because crop growth and yield nonuniformity results from unavoidable nonuniformity of water distribution in the field
6. The presented relationships and methodology can have useful applications in the study of various technical and management factors that affects irrigation uniformity and adequacy, such as irrigation system design, system layout, operation hours, deficit irrigation wind and vapor losses and etc., on crops yield and water productivity.

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محددات تصميم نظام الرى بالرش الثابت لتعظيم إنتاجية المياه تحت الظروف الهامشية

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أجريت تجارب حقلية في سهل الطينة بمحافظة شمال سيناء - مصر في ثلاثة مواسم صيفية متتالية أعوام ٢٠١٢ و ٢٠١٣ و ٢٠١٤ لتقييم تأثير معايير تصميم الري بالرش الدائم (PS) في ظروف هامشية باستخدام رشاشات بقطر فوهات مختلفة مع ضغوط تشغيل مختلفة للوصول الى مدى قيم معامل أنتظامية للمياه كما بالمعاملات. والغرض الآخر هو قياس كفاءة استخدام محصول الدخن العلفى للمياه تحت ظروف البيئة الملحية وعمق المياه المضاف ومدى توفير كمية المياه.تم تقدير قيم معامل التوحيد كريستيانسن (CUc)، وكفاءة استخدام المياه للرى (IWUE)، وفقدان المياه عن طريق الرشح العميق (Dp) وكفاية الري (Pa) من خلال التجارب الحقلية. تم استخدام تصميم القطاعات العشوائية الكاملة مع أربعة مكررات. تتكون المعاملات من خمسة نطاقات مختلفة لمعامل الأنتظامية للري بالرش هى: "CUc1" (٩٠ - ٩٥٪)، و "CUc2" (٨٠ - ٨٥٪)، و "CUc3" (٧٠ - ٧٥٪)، و "CUc4" (٦٥ - ٦٠٪)، و "CUc5" (55 - 50٪).وأشارت النتائج التي تم الحصول عليها إلى ما يلي:القيمة القصوى لكفاية الري كانت ٦٩٪ للمعاملة CUc1، في حين تم الحصول على الحد الأدنى من قيمته (٣٨.٨٪) للمعاملة CUc5. وبزيادة معامل انتظام الري، زادت كفاية الري، في حين انخفض فقدان المياه. وكانت القيمة القصوى لفقدان المياه (Dp) ٢٦.١٥٪ للمعاملة CUc5، في حين كانت القيمة الدنيا ٧٪ للمعاملة CUc1. من خلال خفض معامل انتظام الري (CUc) حدث فاقد كبير من مياه الري (Dp) وكانت العلاقة خطية: $Dp = (-4.809*CUc) + 29.251$ ويعتمد إنتاج علف الدخن على كل من عمق المياه المضاف انتظام الري بالرش، ولكنه أكثر حساسية للتغيرات في عمق المياه المضاف مقارنة بالتغيرات في انتظام الري بالرش. ولذلك، فإن ارتفاع معدل الري بالرش الثابت بالمناطق الهامشية قد لا يعني ارتفاع انتاجيةعلف الدخن، حيث من خلال متوسط عمق المياه المضاف موسميا ١٠٨٦.٨مم، حقق إنتاج محصول الدخن العلفى زيادة معنوية وكان متوسط الانتاج كقيمه قصوى ١٠٩.٣ طن للهكتار. وزاد متوسط كفاءة استخدام المياه من خلال خفض عمق المياه الموسمية وحقق قيمه قصوى ١٠.١ كج للمتر المكعب.يمكن أن تكون هذه الدراسة ذات اهمية فى تطبيقات تحسين التصميم وإدارة وتعزيز نظام الري بالرش الثابت في ظل ظروف هامشية مثل سهل الطينة – مصر.