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REGULAR ARTICLE

Sprinkler irrigation uniformity and crop water productivity of barley in arid region

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ABSTRACT

An investigation has been organized to study the effect of the sprinkler irrigation system design on irrigation uniformity and its impact on barley crop yield and crop water productivity (CWP). The spring irrigation operating pressures (P) were 200 kPa (P1), 250 kPa (P2) and 300 kPa (P3). The sprinkler riser heights were 100 cm (H1), 125 cm (H2) and 150 cm (H3) from the ground. The results demonstrated that the maximum values of coefficient of uniformity (CU) and distribution uniformity (DU) (91.37 % and 0.85, respectively) were obtained at P3H3, while the minimum values (78.21 % and 0.71, respectively) were obtained at P1H1.Under P3H3 treatment, the highest values of 5.50 t ha^{-1} and 63.49 cm of grain yield (GY) and barely plant height (PH), respectively were recorded. The highest CWP value (0.75 kg m^{-3}) was obtained when the P3H3 treatment was applied, while the lowest yield (0.36 kg m^{-3}) was recorded under P1H1 treatment. According to the results of this experiment, under Sebha environmental conditions and similar regions, it is recommended to operate the solid set sprinkler irrigation system at P3H3 to obtain the highest CU and DU and consequently the highest GY, PH and CWP.

Keywords: Arid regions; Barely; Crop water productivity; Sprinkler irrigation uniformity

INTRODUCTION

Barley is one of the most important cereal crops grown in many developing countries, where it is often subject to extreme drought stress that significantly affects production (Ceccarelli et al., 2007). Barley in Libya, it is the second most important cereal crop following wheat (Al-Idrissi et al., 1996). Due to the general decreasing tendency of water availability for agriculture and the increase in energy costs, it becomes even more important to efficiently use water and energy in agriculture (Lopez-Mata et al., 2010). The water utilization efficiency (WUE) or so called crop water productivity (CWP) is very much related to the irrigation methods. Types of irrigation commonly used are; surface irrigation, sprinkler irrigation and drip irrigation (Hanson, 2005). Sprinkler irrigation is becoming a preferred method when the available water for irrigation becomes scarce (Uddin et al., 2013).

In the past few decades, several coefficients of uniformity were developed to express the uniformity of water distribution for different sprinkler irrigation systems (Maroufpoor et al., 2010). Christiansen's coefficient of uniformity (Christiansen, 1942) was first used to express a uniformity coefficient to the sprinkler system (Karmeli, 1978). Distribution uniformity emphasizes the areas which receive the least of irrigation water by focusing on (DU). They suggested that the DU is expressed as a decimal. Thus, both CU and DU coefficients give complementary information. Uniformity is increased when the two coefficients (CU and DU) are closer (Ortíz et al., 2010).

The uniformity coefficient of a sprinkler irrigation system has a direct effect on the system's application efficiency and on the crop yield (Li, 1998; Li and Rao, 2000; Dechmi et al., 2003). Without good uniformity, it is impossible to irrigate efficiently as parts of the field will be either over-irrigated or under-irrigated (Haman et al., 2003).

Therefore, the objectives of this study were to; A) Investigate the effect of the sprinkler parameters (operating pressure and riser heights of sprinkler) on

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sprinkler irrigation uniformity. B) Maximize land and water unit productivity through evaluating the indirect impact of sprinkler parameters on barley crop yield and crop water productivity. C) Set of some recommendations for other regions where environmental and agricultural conditions could be the same.

MATERIALS AND METHODS

A field experiment was conducted at the Experimental Farm of the Faculty of Agriculture, Sebha University, Libya, during the winter season of 2009/2010. Sebha co-ordinates are latitude: 27° 01' N, longitude: 14° 26' E and 432 m above sea level. The soil at the experimental site is sandy (93.90 % sand, 4.00 % silt and 2.10 % Clay). Some physical properties of the experimental soil are given in (Table 1). The experimental arrangement was strip-plot in randomized complete block design. The operating pressures (P) were arranged in the main plots, while the sprinkler riser heights (H) treatments were arranged in the sub-plots.

Barley seeds were planted on the 3rd of December 2009. The seeds were sown at a row spacing of 15 cm at 180 kg ha^{-1}. All Experimental areas received the recommended N fertilizer (180 kg N ha^{-1}) as urea (46 % N). The lengths of the different crop growth stages were 20, 50, 60, and 30 days for initial stage, crop development stage, mid-season stage and late season stage, respectively. At harvest, three units (2m x 2m) were randomly taken from each sub-plot to determine the averages of grain yield (GY) and plant height (PH).

Irrigation treatments

The operating pressures (P) were; 200 kPa (P1), 250 kPa (P2) and 300 kPa (P3). The sprinkler riser heights (H) consisted of 3 levels; 100 cm (H1), 125 cm (H2) and 150 cm (H3) from the ground. The barley plants were irrigated three days intervals using the amounts of applied water as 100% of ETo. Irrigation treatment started after full emergence, and the amount of irrigation water consumed was 7356.9 m^3 ha^{-1}.

Sprinkler irrigation system

The solid set sprinkler system was used to investigate the effect of the operating pressures and riser heights of sprinkler on irrigation uniformity and its reflection on barley crop yield and crop water productivity. The discharge from the sprinkler jet was measured volumetrically by placing two flexible hoses over the sprinkler nozzles and receiving the flowing water in a calibrated container. The field experiment consisted of 6 laterals of sprinkler irrigation covering the study area. The sprinkler lateral included six rotating sprinklers. Each 2 laterals (main plot) composed of 3 sub-plots. The size of each sub-plot was 12m×12m whereas the risers were installed at the corners of each sub-plot. The sub-plots were isolated with 12 m (around the sub-plot) fallow soil as a buffer zone to avoid interference between adjacent sub-plots. Each sub-plot was divided into a grid of thirty six units (2m×2m). Thirty six catch-cans were placed at the center of each unit above the soil surface. Each lateral had one flow meter, one pressure regulator and pressure gauge to control the operating pressure and measure the quantity of applied irrigation water. Catch-cans of 120 mm diameter and 200 mm height were used to collect irrigation water. The catch-can reading process was carried out as quickly as possible with the aim of reducing evaporation losses in collectors. The collected water depth was calculated by dividing the volume caught by the open area of the catch-can.

Table 1: Some physical properties of different soil layers of the experimental soil

Depth (cm)	Field capacity (%)	Wilting point (%)	Available water (%)	Bulk density (g/cm³)
0-20	11.5	5.6	5.9	1.51
20-40	11	5.3	5.6	1.61

Uniformity evaluation

Tests have one hour duration for each treatment. Once the test is over, the water collected in each catch-can is measured volumetrically with a calibrated test tube. For each treatment, coefficient of uniformity (CU), distribution uniformity (DU) and coefficient of variation (CV) are determined as the follows:

Coefficient of uniformity

The Coefficient of uniformity (CU) is commonly used in agricultural sprinkler uniformity assessment was expressed as (Christiansen, 1941; ASAE, 2001):

$$CU = [\ 1 - \frac{\sum_{1}^{n} \left| Xi - X^{-} \right|}{n.X^{-}}\ ] \times 100 \qquad (1)$$

Where:

Xi = The water depth collected by catch can No. i, (mm),
X^- = Average water depth collected in all catch cans (mm),
N = The total number of catch cans.

Distribution uniformity

The distribution uniformity (DU) was calculated using the eq. (2) (Merriam and Keller, 1978):

$$DU = \frac{ADC_{25}}{X^{-}} \times 100 \qquad (2)$$

Where: ADC_{25} is the lowest quarter of the average water depth of catch cans.

Coefficient of variation

The coefficient of variation (CV) is the quotient between the standard deviation of the applied water depths (σ) and the average of water depth collected according to ASAE (1991):

$$CV = \frac{\sigma}{\bar{X}} \quad (3)$$

Where: σ is the standard deviation of the water depth of catch-cans.

The daily ETo

It was calculated from weather data according to the equation of FAO-PM (Allen et al., 1998) as eq. (4):

$$ETo = \frac{0.408 \cdot \Delta(R_n - G) + \gamma \cdot \frac{900}{T+273} \cdot u_2 \cdot (e_s - e_a)}{\Delta + \gamma(1 + 0.34 \cdot u_2)} \quad (4)$$

Where:

Δ = Slope of the saturation vapor pressure curve at air temperature (kPa °C^{-1}),
R_n = Net radiation at the crop surface (MJm^{-2} d^{-1}),
G = Soil heat flux density (MJm^{-2} d^{-1}),
γ = Psychometric constant = $0.665\times10^{-3}\times P$, kPa °C^{1} (Allen et al., 1998),
U_2 = Wind speed at 2 m height (m s^{-1}),
e_s = Saturation vapor pressure (kPa),
e_a = Actual vapor pressure (kPa),
$(e_s - e_a)$ = Saturation vapor pressure deficit (kPa),
T_{mean} = Mean daily air temperature at 2m height (°C).

The average daily ETo in Sebha region was estimated using the monthly mean weather data for a 15-year period (January 1994–December 2008) of Sebha climatological station. The average of daily ETo in Sebha was 3.88, 3.69, 4.73, 7.14 and 9.86 ETo mm day^{-1} in Dec., Jan., Feb., Mar. and April months, respectively.

The crop water requirements (ETc)

It was estimated using the crop coefficient according to Eq. (5):

$$ET_c = ET_o \times K_c \quad (5)$$

Where:

ET_c = Crop water requirements, mm/day.
K_c = Crop coefficient.

The crop coefficients (Kc) of initial, mid and end stage were 0.30, 1.15 and 0.25, respectively according to Allen et al. (1998).

Amounts of irrigation water

It was calculated according to the eq. (6):

$$IWA = \frac{A \times ETc \times Ii}{Ea \times 1000} + LR \quad (6)$$

Where:

IWA = Irrigation water applied, (m^3),
A = Plot area, (m^2),
ETc = Crop water requirements, (mm day^{-1}),
Ii = Irrigation intervals, (day),
Ea = Application efficiency, (%), (Ea = 70%),
LR = Leaching requirements (m^3).

Crop water productivity

Crop water productivity (CWP), Kg m^{-3} which defined as water utilization efficiency was calculated according to Doorenbos and Pruitt (1977) as follow:

$$CWP = \frac{\text{Grain yield (kg ha}^{-1})}{\text{irrigation water applied (m}^3\text{ ha}^{-1})} \quad (7)$$

Statistical analysis

The obtained data were subjected to analysis of variance as described by Gomez and Gomez (1984). The homogeneity test was performed using the method described by Snedecor and Cochran (1980). The combined analysis was done for irrigation system to study the effect of this variable and the interactions involved. Means were compared using least significant difference (LSD) method at 5 % level of probability in both seasons.

RESULTS AND DISCUSSION

Effect of operating pressure on sprinkler irrigation uniformity

Table (2) shows the values of CU, DU and CV resulted from testing different operating pressures and riser heights. The CU values were always higher than those of DU. As shown in Table (2), the CU and DU were increased with increasing operating pressure (P). Data of this study reveal that the average of maximum values of CU and DU (87.03 % and 0.81, respectively) were obtained at P3. In contrast, the average of minimum values (82.48% and 0.74, respectively) was obtained at P1. This trend was also shown by Suharto and Susanawati (2012). The highest value of CU (91.37%) was recorded at P3 (300 kPa), while the lowest value (78.21%) was noted at P1 (200 kPa). This result is found to be in full agreement with Topak et al. (2005). They recommended that the sprinkler irrigation system should operate between 200 and 350 kPa. Therefore, to obtain the highest CU and DU, the sprinkler irrigation system must operate at pressure of P3.

The lowest P (P1) was found to cause a reduction in throw radius. These reductions may result in sprinkler overlap changing and this will reduce the water distribution uniformity. The reduction in the water distribution uniformity indicated that the sprinkler irrigation was not too good in delivery of water irrigation average, so the crops would not receive the same amount of water. Keller (1983) reported in his study, in a given sprinkler, reported that as the operating pressure lowers, the dispersion was intensified and water drops hit the ground with greater effect that will decrease the water distribution uniformity.

Data illustrated in Table (2) clearly show that when the operating pressure was increased from 200 to 250 kPa (25%) and from 200 to 300 kPa (50 %), the CU increased from 3.2% to 5.5%, respectively. The results reveal that the relation was not linear. This result is in full agreement with Moazed et al. (2010).

In addition, the CV decreased gradually with the increase in P. The maximum value of CV (21.60 %) was obtained at the lowest operating pressure (P1), while the minimum value (15.63%) was obtained at P3. The CV value at P1 was the highest among all values of all operating pressures. It exceeded the values obtained with P2 and P3 by 17.96 and 27.64%, respectively. Therefore, to obtain the lowest CV, the sprinkler irrigation system must operate at the pressure level of P3.

Effect of riser height on sprinkler irrigation uniformity

Regarding riser height (H) effect, the CU and DU values were increased with increasing H. CU values increased by 6.12 and 10.15 % when H1 was increased to H2 and H3, respectively. However, the highest and the lowest values of CU were recorded at H3 (88.69%) and H1 (80.52%), respectively. This result occurred because some soil points received larger amount of water, whereas water distribution at other points was very scarce.

Table 2: The effects of operating pressure and riser height on uniformities (CU, DU and CV) values

Operating pressure	Riser height	Uniformities		
		CU (%)	DU	CV (%)
P1	H1	78.21	0.71	24.71
	H2	83.39	0.74	22.37
	H3	85.84	0.76	17.74
	Average	82.48	0.74	21.60
P2	H1	80.69	0.73	21.61
	H2	85.91	0.79	16.68
	H3	88.86	0.79	14.86
	Average	85.16	0.77	17.72
P3	H1	82.66	0.75	22.15
	H2	87.05	0.83	14.42
	H3	91.37	0.85	10.33
	Average	87.03	0.81	15.63
Average of H	H1	80.52	0.73	22.82
	H2	85.45	0.79	17.82
	H3	88.69	0.80	14.31

The average values of DU overall H were 0.73, 0.79 and 0.80 for H1, H2 and H3, respectively. This means that DU was increased by 7.37 and 9.00% as riser height increased to H2 and H3, respectively (Table 2).

CV value at the lowest riser height H1 was higher than those at H2 and at H3 by 21.90 and 37.30%, respectively.

Both CU and DU were increased with the increase in both P and H. Under P1 combined with different H (H1, H2 and H3), the CU were 78.21, 83.39 and 85.84 %, respectively. The corresponding values for DU were 0.71, 0.74 and 0.76, respectively. At H3, values were 82.66, 87.05 and 91.37 % for CU and 0.75, 0.83 and 0.85 for DU, in the same order (Table 2).

Data also reveal that the maximum values of CU and DU (91.37 % and 0.85) were obtained at P3H3. In contrast, the minimum values (78.21% and 0.71) were obtained at P1H1.Therefore, to obtain the highest CU and DU, the sprinkler irrigation system must operate at the high levels used of both pressure and riser (P3 and H3).

The CV was reduced by increasing P and H. The lowest CV value (10.33%) was recorded under the highest P and H treatment (P3 and H3). On other hand, the highest CV value (24.71%) was recorded under the lowest P and H treatment (P1 and H1). Therefore, to obtain the lowest CV, the sprinkler irrigation system must operate at P3 and H3.

Correlation coefficient

As shown in (Fig. 1), CU was consistently higher than DU and both are inversely related to CV. This result is found to be on line with the finding obtained by Keller and Bliesner (2000). They reported that, according to the mathematical relationship between CU and DU, CU will always be larger

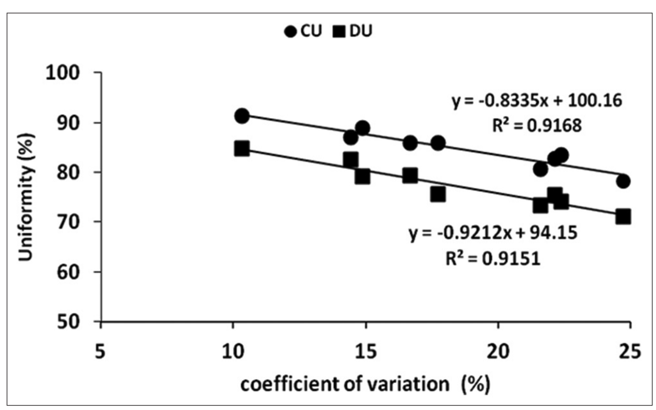

Fig 1. Relationships between DU and CU with CV.

(when both are in decimals or in a percentage) since positive and negative deviations from the mean application volume are used in calculating CU. But, only negative deviations are used in the calculation of DU. Both CU and DU is linearly related to CV (Fig. 1). Similar results were reported by Tarjuelo et al. (1999).

As shown in (Fig. 1), the obtained relation between CU and DU against CV were:

CU = 100.16 -0.83CV, R^2 = 0.92, DU = 94.15 -0.92CV, R^2 = 0.92

Effect of operating pressure and riser height on barley crop

Both operating pressure and riser height will affect uniformity which will consequently affect GY and PH. Data presented in Table (3) show the effect of operating pressure and riser height on grain yield (GY) and plant height (PH).

H3P3 treatment recorded the highest values of GY and PH (5.50 t ha^{-1}and 63.49 cm, respectively) as compared with other treatments. Meanwhile, H1P1 collected the lowest values for previous parameters 2.63 t. ha^{-1} and 38.82 cm, respectively. In this concern, Li and Rao (2000) and Dechmi et al. (2003) indicated that the uniformity coefficient of a sprinkler irrigation system has a direct effect on the crop yield. In contrast, H1P1 recorded the lowest CU (78.21%). Haman et al. (2003) proved that, without a good uniformity, it is impossible to irrigate efficiently; parts of the field will be either over-irrigated or under-irrigated, and consequently the reduction in yield will be obtainable.

Table 3: Effect of sprinkler irrigation system parameters (P and H) on grain yield, crop height and crop water productivity

Operating pressures	H1	H2	H3	Mean
		Grain yield (t ha^{-1})		
P_1	2.63	2.77	3.23	2.88
P_2	3.5	3.77	4.2	3.82
P_3	4.53	4.9	5.5	4.98
Mean	3.56	3.81	4.31	3.89
$LSD_{0.05}$ for P=0.52**				
$LSD_{0.05}$ for H=0.687*				
$LSD_{0.05}$ for P×H=NS				
		Crop height (cm)		
P_1	38.82	41.59	43.95	41.45
P_2	46.5	49.48	50.63	48.87
P_3	52.12	55.82	63.49	57.14
Mean	45.81	48.96	52.69	49.16
$LSD_{0.05}$ for P=6.29**				
$LSD_{0.05}$ for H=9.613*				
$LSD_{0.05}$ for P×H=NS				
		CWP (kg m^{-3})		
P_1	0.36	0.38	0.44	0.39
P_2	0.48	0.51	0.57	0.52
P_3	0.62	0.67	0.75	0.68
Mean	0.48	0.52	0.59	0.53
$LSD_{0.05}$ for P=0.072**				
$LSD_{0.05}$ for H=0.072*				
$LSD_{0.05}$ for P×H=NS				

F test: * and ** significant at 0.05 and 0.01 probability levels, respectively, NS: Not significant

Data illustrated in (Fig. 2) clearly show that, values of GY and PH under P3H3 treatment were higher than those obtained under P1H1, P1H2, P1H3, P2H1, P2H2, P2H3, P3H1 and P3H2 treatments by 108.9 and 63.5, 98.8 and 52.6, 70.1 and 44.5, 57.1 and 36.5, 46.0 and 28.3, 31.0 and 25.4, 21.3 and 21.8, and 12.2 and 13.7%, respectively, for GY and PH, respectively. Therefore, it's recommended to operate the solid set sprinkler system at P3H3 to obtain the highest CU, GY and PH values.

Effect of operating pressure and riser height on crop water productivity

As shown in (Table 3), crop water productivity (CWP) was significantly affected by different operating pressures and riser heights. The averages of CWP were 0.48, 0.52 and 0.59 kg m^{-3} for H1, H2 and H3 treatments, respectively, and were 0.39, 0.52 and 0.68 kg m^{-3} for P1, P2 and P3, respectively. The highest CWP value (0.75 kg m^{-3}) was obtained when P3H3 treatment was applied. Meanwhile, the lowest one (0.36 kg m^{-3}) was recorded under P1H1 treatment. These results are noticed to be in the same trend with data of Table (2), where H3P3 treatment was generated the highest CU (91.37%). This result indicated that, a good uniformity coefficient increased the crop yield and positively reflected in CWP, while H1P1 treatment was resulted in its application the lowest CU (78.21%). This result indicated that without a good uniformity, the reduced crop negatively reflected in CWP. Results of Espinoza et al. (2004) which evaluated the uniformity of sprinkler irrigation and its effect on crop yield, they stated

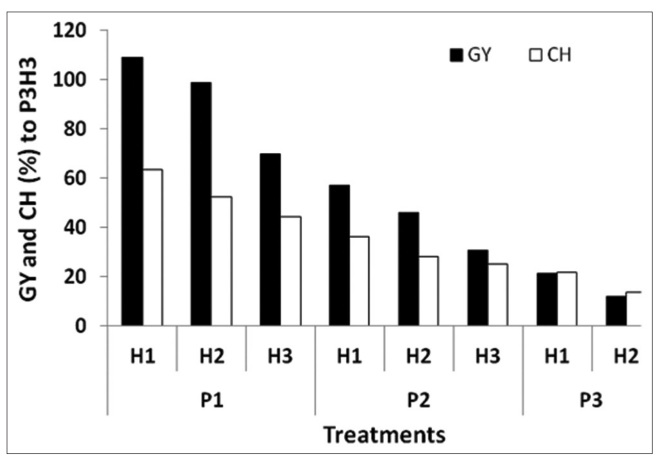

Fig 2. Grain yields (GY) and crop height (CH) of P3H3 treatment against other treatments.

that the regression models show that the yields increase in proportion to the uniformity coefficients, which indicates that the better the distribution of water in the field, the higher crop yield.

CONCLUSION

From the above mention results of this study, both coefficient of uniformity and distribution uniformity of sprinkler irrigation system were increased with increasing both the operating pressure up to 300 kPa and riser height till 1.5 m of sprinkler from ground level. Moreover, reflected on increasing grain yield of and crop water productivity of barley. Therefore, under Sebha environmental conditions and similar regions, concerning to the previous results, we recommend to operate the solid set sprinkler irrigation system at the mentioned highest operating pressure and riser height of sprinkler to obtain the highest coefficient of uniformity and distribution uniformity positively reflecting in the grain yield, barely crop height and crop water productivity.

Authors' Contributions

M. H. Abd El-Wahed: Main researcher collected and analyzed the data. A. E.: Supported in data analyze, providing literature and wrote article. A. A.: Supported in providing literature. H. S. and C. B.: Proofreading and corrected the article.

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