Effect of Design Parameters of Sprinkler, Sowing Date on Heat Stress and Millet Crop Productivity

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ABSTRACT

Millet is a type of C_4 grass that grows best in warm, dry climates. Because water is often scarce in these areas, farmers are always looking for ways to grow millet while using less water. This is called improving water use efficiency (WUE). Field experiment was conducted in the 2023 growing season at Maryout research station, Desert Research Center, Egypt to evaluate the effect of design parameters of sprinkler, sowing date on heat stress water use efficiency and Millet crop productivity. The experiment was sown with Millet seeds on two dates. The first was 25 June (S1) and the second was 10 July (S2). Two nozzles' diameters 3.2 mm and 3.9 mm were compared under three different riser heights 1.0 m, 1.20 m and 1.40 m to study the impact of sprinkler height and nozzle diameter on the two different dates (S1, S2) on biomass of Millet crop. It is recommended to use this schematic model representation of the of the system conception, which represents the behavior of the system. There is a significant response between (Yield), growing degree-days (AGDD), Sprinkler height (L), water quantity (Q) and Sprinkler Nozzle diameter (N) with R2 more than 0.90.

Keywords: Sprinkler irrigation; Millet crop; sowing date; heat units and productivity.

INTRODUCTION

Temperature is a critical factor that determines climate and possibly the achievable productivity of crops (Kalra *et al.,* 2008). The phenological development of most plants from germination to maturity is closely linked with temperature and the heat accumulation on a daily basis. Although the amount of heat units required to move the plant to the next developmental stage remains the same every year, the time taken (in days) may vary greatly from one year to another because of changes in weather conditions. For instance, the temperature that is necessary for millet to grow at least to some extent is about 10°C per day. It prefers a mean daily temperature of between 15 and 20°C for its growth (Opole *et al.,* 2018). Overall, the optimization of millet production requires the improvement of all the factors that define the agricultural system, (climate and water resource management), to reach the maximum value. The duration (in days) may vary from year to year due to the variation in the weather conditions prevailing at the time of the study. For example, the minimum temperature at which millet can be observed to grow is roughly 10°C per day. The optimal mean daily temperature for its growth lies between 15 and 20°C (Opole *et al.*, 2018). In general, the production of millet requires the promotion of all agricultural system parameters, including climate and water resource management, to attain the highest value.

The pearl millet crop demonstrates moderate sensitivity to water stress. Implementing irrigation for pearl millet in sandy soils at a rate of 100% ETo can conserve 38% of the applied irrigation water, achieving a water use efficiency of 7.55 kg green yield per cubic meter of water consumed, and a water productivity of 6.73 kg green yield per cubic meter of water applied (Taha and Ghandour, 2021). The highest water use efficiency (6.13 Mg ha^{-1} mm^{-1}) was recorded in tilled soil, attributed to a greater leaf area index and dry matter production compared to no-till conditions (Crookston *et al.*, 2020). The aim of research was to study the impact of sprinkler height on some soil physical properties of Maryout research station and the effect of climate change represented by different sowing dates on millet biomass yield.

MATERIALS AND METHODS

Field experiment were conducted in the 2023 growing season at Maryout research station, Desert Research Centre (DRC) (31° 00′ 23.51″ N, 29° 47′ 24.17″ E Alexandria Gov., Egypt. The experimental site is situated within an arid region characterized by a Mediterranean climate. The site's elevation is approximately 13 meters above sea level. Annual precipitation averages 151m, with mean annual temperature around 20.6°C. Relative humidity typically hovers around 71.6%, and wind speeds commonly reach 5.4 m/s. Annual reference evapotranspiration (ETo) is substantial, reaching 1481 millimetres per year (Table 1).

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Table 1. Climatic data at Maryout research station-DRC

Month	Prec.	Tem. max	Tem. min.	Hum.	Sun shine	Wind (2m)	ETo
	mm/m	°C	°C	%	%	m/s	mm/d
Jan	51	15.5	12.9	67.9	61.7	6.6	2.58
Feb	19	16.3	13.2	65	67.4	5.9	2.93
Mar	23	15.8	12.7	65.1	67.6	6.4	3.39
Apr	0	20.5	16.2	70.9	71.6	5.4	4.30
may	1	21.6	19.2	77.7	74.9	5.2	4.48
Jun	0	24.9	23.3	81.4	83.6	5	5.20
Jul	0	26.3	25.1	82.6	84.1	5.3	5.48
Aug	0	27.4	26.1	78.7	84.7	4.9	5.35
Sep	0	27.3	25.2	69.8	80.6	5.2	5.03
Oct	11	24.5	23	68	74.5	5.4	4.13
Nov	15	22	19.5	63.7	71.4	4.7	3.23
Dec	31	20.1	17.5	68.7	63.8	4.8	2.52
Total	**151**						

"Precipitation (Prc.), minimum and maximum temperatures (Tem. min/max), relative humidity (hum.), sunshine duration as a percentage of day length (Sun shine), wind speed at 2m. Above the ground (Wind (2m)), and Reference Evapotranspiration (ETo), as sourced from FAO AQUASTAT (2022)."

Crop water requirements and the volume of water applied were determined following the methodology outlined in FAO Irrigation and Drainage Paper No. 56: "Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements" (Allen *et al.*, 1998).

To calculate these values, we utilized average Reference Evapotranspiration (ETo) data in conjunction with crop-specific coefficients (Kc) obtained from Table (2).

Consequently, the total amount of water used for Millet is 490 mm which cultivated on 25th June. Further; irrigation system based on sprinklers which pinned with two different nozzles [N1 = nozzle diameter 3.2 mm ($0.55m^3/h$) and N2 = nozzle diameter 3.9 mm ($0.86m^3/h$)]. In addition, installed sprinkler with three heights [L1 = sprinkler height (1.0m), L2 = sprinkler height (1.2m) and L3= sprinkler height (1.4m)]. Finally, Millet was cultivated on 25th June (S1) and 10th July 2023 (S2) (Fig. 1).

Table 2. Average crop coefficients (Kc) for Millet

Item	Growth stage				Total.
	Init.	Dev.	Mid.	Late.	
Days	20	30	55	35	140
KC	0.3	1.00	1.00	0.3	

Fig. 1. Experimental layout and distribution treatments: (A) Sprinkler nozzle; (B) Sowing date treatments, where S1 = Sowing date 25th June, S2 = Sowing date 10th July, L1 = sprinkler height (1.0 m), L2 = sprinkler height (1.2 m), L3= sprinkler height (1.4 m) N1 = nozzle diameter 3.2 mm (0.55 m^3/h), N2 = nozzle diameter 3.9 mm. (0.86 m^3/h)

Growing Degree-Days (heat units) (GDD)

The single sine curve approach (Baskerville & Emin, 1969 and Griogorieva *et al.*, 2010) was used to determine growth degree days (GDD) or heat units during the Millet crop's growing season. This basic linear method just requires daily minimum and maximum air temperatures reported by the local meteorological weather station at the experiment location. Eq. (1) explains how to calculate increasing degree days:

$$GDD = [(T_{max} + T_{min}) / 2] - T_{base} \quad (1)$$

Where: T_{max} and T_{min} represent the daily maximum and minimum temperatures in degrees Celsius (°C), and T_{base} is the base temperature in degrees Celsius (°C).

Heat Use Efficiency (HUE) is defined as the ratio of crop yield to the accumulated growing degree days, as described by Kingra and Kaur (2012) in Eq. (2).

$$HUE = Yield\ (Ygi) / (AGDD). \quad (2)$$

Where: HUE represents Heat Use Efficiency, expressed in (kg. fed^{-1}. $°C^{-1}$. day^{-1}), Ygi denotes the Economic Yield, measured in(kg.$fed.^{1}$) and, AGDD signifies Accumulated Growing Degree Days, expressed in (°C day).

Heat units, frequently employed in agricultural studies, serve as an indicator of plant developmental progress. As documented by Snyder *et al.* (1999), developmental rates exhibit a generally linear relationship with air temperature. So greater or lower temperatures will have an impact on crop development and output. So, the lower temperature (T_{base}) was fixed to 10°C (Opole *et al.*, 2018).

Irrigation water use efficiency using the Bos (1979) and Little *et al.* (1993) Eq. (3):

$$IWUE = [Y_{gi} – Y_{gd}]/ IRR_i \quad (3)$$

Where: IWUE = Irrigation Water Use Efficiency (kg. m^{-3}).

Ygi = Economic Yield ($kg.fed^{-1}$). Ygd = Crop Yield ($kg.fed^{-1}$), (Specifically, the yield of the crop in the absence of irrigation)*, IRRi = The volume of irrigation water applied ($m^3. fed^{-1}$)

* In numerous semiarid to arid regions, it is common for Y_{gd} to be zero.

Data analysis was conducted using a two-way ANOVA with a split-plot design, followed by Duncan's HSD test at p<0.05 significance level. The analysis was performed using the statistical software package COSTAT 3.03. Subsequently, simple linear regression models were developed, incorporating relevant predictor variables.

X1;……. ;X_p can be describe by Eq. (4).

$$y = B_0 + B_1X_1 + \ldots\ldots + B_pX_p + k \qquad (4)$$

Where:

y: The dependent variable. X1, X2,...,Xp: Independent variables or predictors. B0: The intercept of the regression line. B1, B2, ..., Bp: Regression coefficients representing the slope of the line for each predictor variable. k: The error term, representing the variability not explained by the model, which is assumed to be constant for all values of the predictors."*

RESULTS AND DISCUSSIONS

Accumulated Growing Degree Days (AGDD):

Table (3) presents the average 10-day monthly, actual and adjusted temperatures, growing degree days (GDD), and accumulated growing degree days (AGDD) throughout the Millet cultivation period; it is evident that the total heat units necessary for Millet to progress from the initial stage to the final stage in its life cycle amounted to 2306.4 and 2054.5C°/season, for sowing dates of 25th June (S1) and 10th July (S2) concurrently.

As shown in Fig. (2); with different sowing date treatments the biomass yield for Millet has significant different value where biomass yield under (S1) recorded a highest value comparing with S2 treatment by (57.65 and 56.87 $ton.fed^{-1}$) concurrently. It is mean the (1 $Ton.fed^{-1}$) biomass yield of Millet needs for (40.007 and 36.12 heat units) as an average under varied sowing dates (25th June and 10th July), respectively. In addition; yield obtained a highest value (58.2 $ton.fed^{-1}$) under sprinkler height (L3) comparing with other sprinkler heights treatments (L1 and L2). Further; there are a liner regression between AGDD and yield of Millet where, by increasing heat unit from 1647.7 C°.day to 2306.4 C°.day. Millet yield increase from (38.01 Ton .fed to 57.6 $Ton.Fed^{-1}$) (Fig. 3). Developmental rates rise about linearly as a function of air temperature (Snyder *et al.*, 1999), the following model can be summarizing this liner regression (Eq. 5).

$$Y_{Millet} = 0.029\ (AGDD) - 8.735 \qquad (5)$$

Where: -

Y_{Millet} = Biomass yield for Millet ($Ton.\ fed^{-1}$).

AGDD = Accumulative of growing degree-days (c° day) [$2054.5 \leq AGDD \leq 2306.4$]

Table 3.Decadal Mean Temperature, Growing Degree Days (GDD), and Accumulated Growing Degree Days (AGDD) during the Wheat Growing Season

Month	Sowing date 25th June					Sowing date 10th July				
	Date	T_{max}	T_{min}	GDD	AGDD	Date	T_{max}	T_{min}	GDD	AGDD
2023	D	C°	C°	C°	C° day	D	C°	C°	C°	C° day
June	1 – 10	*	*	*	*	*	*	*	*	*
	11–20	*	*	*	*	*	*	*	*	*
	21-30	33.0	21.7	86.9	86.9	*	*	*	*	*
July	1-10	33.5	23.2	183.3	270.2	1-10	33.5	23.2	18.3	18.3
	11.20	33.4	23.1	182.2	452.4	11-20	33.4	23.1	182.2	200.5
	21-30	37.2	24.9	210.6	663.0	21-30	37.2	24.9	210.6	411.1
August	31-9	36.2	24.4	203.0	865.9	31-9	36.2	24.4	203.0	614.0
	10-19	33.0	24.2	185.9	1051.8	10-19	33.0	24.2	185.9	799.9
	20-29	35.0	24.5	197.4	1249.2	20-29	35.0	24.5	197.4	997.3
September	30-7	35.7	24.7	202.0	1451.2	30-7	35.7	24.7	202.0	1199.3
	9-18	34.3	25.0	196.6	1647.7	9-18	34.3	25.0	196.6	1395.9
	18-27	33.9	22.9	183.6	183.3	18-27	33.9	22.9	183.6	1579.4
October	28-8	31.5	23.0	172.7	2004.0	28-8	31.5	23.0	172.7	1752.1
	9-18	29.2	21.3	152.2	2156.1	9-18	29.2	21.3	152.2	1904.3
	19-28	30.2	19.9	150.3	**2306.4**	19-28	30.2	19.9	150.3	**2054.5**

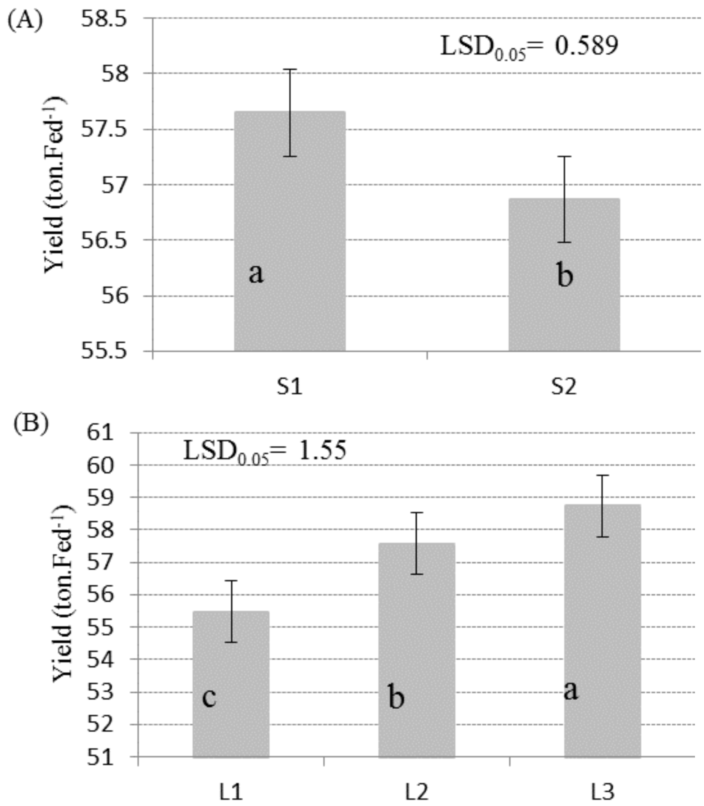

Fig. 2. Millet mean yield as affected by: (A) Sowing date treatments; (B) sprinkler height treatments, where lowercase letters above columns indicate significant differences at *p* < 0.05, LSD0.05 = least significant difference, error bar = ±SD, S1 = Sowing date 25th June, S2 = Sowing date 10th July, L1 = sprinkler height (1.0m), L2 = sprinkler height (1.2m), L3= sprinkler height (1.4m)

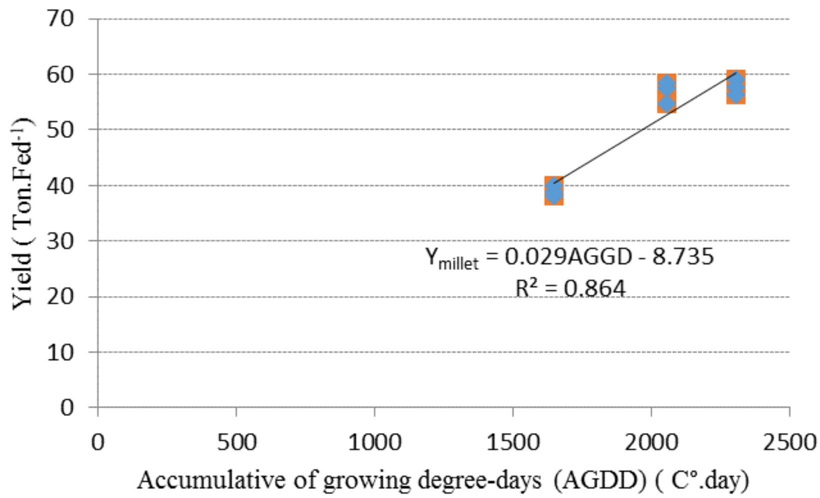

Fig. 3. Impact of Accumulated Growing (Degree-Days) on Millet Yield under Different Treatments

Additionally, data regarding heat use efficiency (HUE) were collected as detailed in Table (4) under various treatment conditions. The peak value for HUE was recorded at a sprinkler height of (L3) and a sowing date of 10th July, measuring (27.02 & 27.68 Kg. fed^{-1} C^{-1} day^{-1}) respectively. This is attributed to the efficiency of heat utilization for dry matter accumulation, which is contingent upon crop variety, genetic traits, and sowing timing, and holds significant practical implications (Rao *et al.,* 1999). Conversely, the lowest HUE value was noted under the sowing date of 25th June (S2), which recorded (24.99 Kg. fed^{-1} $C^{-1}day^{-1}$), and under the sprinkler height of (L1), which was (25.5 Kg. fed^{-1} $C^{-1}day^{-1}$). Ultimately, the most synergistic effect among treatments was observed with the sowing date of 10th July in conjunction with the sprinkler height (L3). Additionally, the heat units at the beginning of July may exert a more pronounced influence on the cultivation and phenology of Millet compared to alternative sowing dates. Therefore, the efficiency of heat utilization in terms of dry matter accumulation relies on crop type, genetic factors, and sowing timing, which has significant practical applications (Rao *et al.,* 1999). Moreover, Millet is characterized by a high nutritional profile, particularly in calcium, iron, and manganese (Gull *et al.,* 2015), and is suitable for prolonged storage due to its reduced vulnerability to pests (Vietmeyer, 1996). Consequently, Millet possesses immense potential to address the challenges posed by climate change (Pallante *et al.,* 2016).

Millet production and Irrigation water use efficiency (IWUE).

In Fig. (4), data points that are variations in yield values due to the varied treatments. For instance; treatment (L3) had the greatest yield value of 58.2 $Ton.Fed^{-1}$, which is a considerable value when compared to the other treatments (L2 and L1), which had low values of 56.4 and 54.8 $Ton.Fed^{-1}$ respectively. Meaning that the sprinkler height (L3=140cm) improved yield of Millet by 6.2% comparing with crop yield under sprinkler height (L1 = 100cm). On the other hand, data under sprinkler nozzle treatments have not a significant value differentiation but highest yield value observed under (N2) by (57.6 $Ton.fed^{-1}$) and lowest value under (N1) by (55.3 $Ton.fed^{-1}$).

Irrigation Water Use Efficiency (IWUE) for Millet:

Irrigation water use efficiency (IWUE) Data in Table (5) demonstrate that there is a major influence on Nozzles treatments and sprinkler height. There are a positive effect for (N2) treatment compare with (N1); where, IWUE was recorded (26.6 $Kg.m^{-3}$) under Nozzle (N2) but with Nozzle (N1) treatment the value was (22.86 $Kg.m^{-3}$). Thus; there are a linear relation between Nozzles discharge and IWEU; whereas, by increasing nozzles discharge from (550Lph to 860Lph) the IWUE increase significantly by (16.3%). In addition; by increasing sprinkler height from (1.00 to 1.2 to 1.4 m) IWUE increase significantly from (24.0 to 24.7 to 25.5 $Kg.m^{-3}$) respectively. Elevated irrigation efficiency results in reduced operational expenses; enhanced productivity per unit of water supplied, alongside improved environmental benefits and management practices (Irmak *et al.,* 2011). Misapplication of efficiency terminology may result in a distorted representation of the performance of an irrigation system. Consequently, it is crucial for both agricultural producers and irrigation management experts to carefully select the relevant efficiency and uniformity metrics when assessing irrigation systems.

Table 4. Heat uses efficiency (HUE) under different sowing date and sprinkler height treatments

ITEMS	Treatments				
	L1	L2	L3	S1	S2
	(Kg. fed^{-1} $C^{-1}day^{-1}$)				
HUE	$25.50^{C} \pm 1.72$	$26.49^{b} \pm 1.82$	$27.02^{a} \pm 1.82$	$24.99^{b} \pm 1.17$	$27.68^{a} \pm 1.20$
$LSD_{0.05}$	0.528			0.175	

$LSD_{0.05}$ = least significant difference, Values (mean ±SD) followed by the same lowercase superscript are not significantly different ($p < 0.05$), L1 = sprinkler height (1.0m), L2 = sprinkler height (1.2m), L3= sprinkler height (1.4m), S1 = Sowing date 25th June, S2 = Sowing date 10th July.

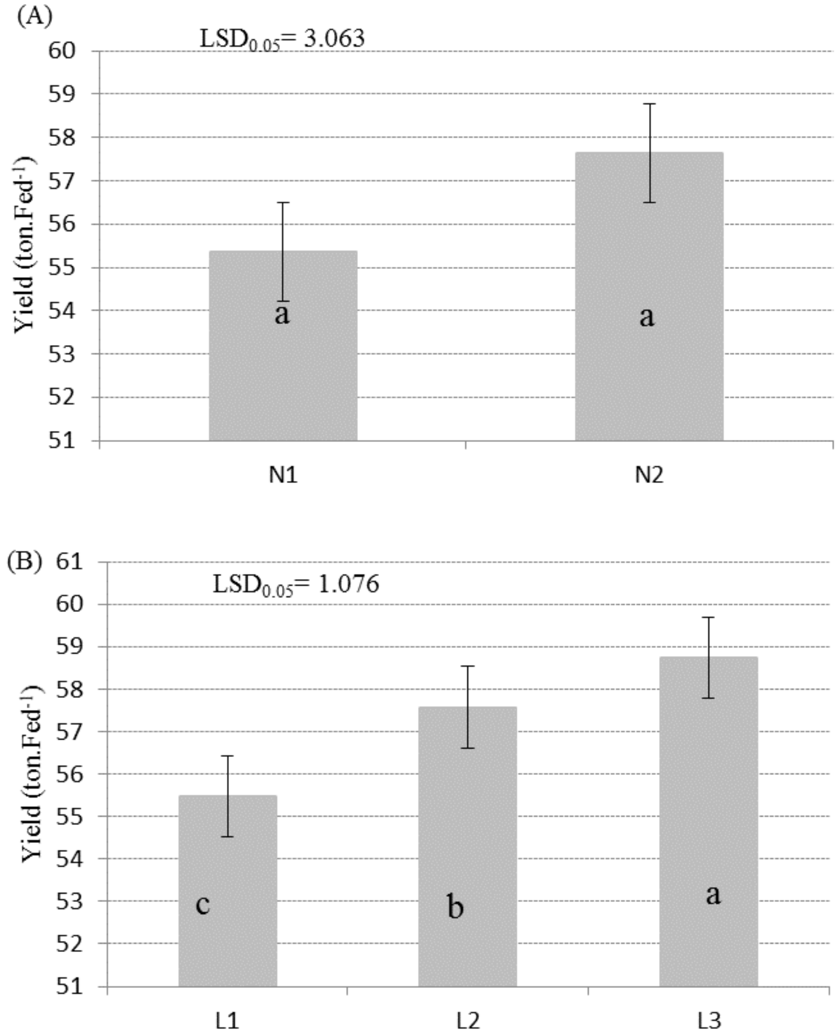

Fig. 4. Millet mean yield as affected by: (A) sprinkler Nozzle treatments; (B) sprinkler height treatments, where lowercase letters above columns pointed to significant differences in p<0.05, LSD0.05 = low significant difference, error bars = ±SD, N1 = nozzle diameter 3.2 mm(0.55m^3/h), N2 = nozzle diameter 3.9 mm. (0.86m^3/h), L1 = sprinkler height (1.0 m), L2 = sprinkler height (1.2 m), L3= sprinkler height (1.4 m)

Table 5. Irrigation water use efficiency (IWUE) under different sowing date and sprinkler height treatments

ITEMS	**Treatments**				
	L1	**L2**	**L3**	**N1**	**N2**
			(Kg. m^{-3})		
IWUE	$24.0^C \pm 2.388$	$24.7^b \pm 2.245$	$25.5^a \pm 2.12$	$22.86^b \pm 0.82$	$26.6^a \pm 1.03$
$LSD_{0.05}$		0.474		1.376	

$LSD_{0.05}$ = least significant difference, Values (mean ±SD) followed by the same lowercase superscript are not significantly different ($p < 0.05$), L1 = sprinkler height (1.0m), L2 = sprinkler height (1.2m), L3= sprinkler height (1.4 m), N1 = nozzle diameter 3.2 mm (0.55 m^3/h), N2 = nozzle diameter 3.9 mm. (0.86 m^3/h).

Occasionally; a model is a schematic depiction of the concept of a system, an act of imitation, or a collection of equations that represent the behavior of a system (Murthy, 2003). Thus, there is a substantial response among (Yield), AGDD, Sprinkler height (L), water quantity (Q) and Sprinkler Nozzle diameter (N) with R^2 more than 0.90 (Eq. 6).

$$Y_{Millet} = 44.9 - 0.0007\,(Q) + 0.0003\,(AGDD) + 0.0203\,(L) + 3.25(N) \quad (6)$$

Where: -

Y_{Millet} = Biomass yield for Millet (Ton. fed^{-1}).

AGDD = Accumulative of growing degree-days (C°.day) [$2054.5 \leq AGDD \leq 2306.4$]

Q = Total water applied ($m^3.fed^{-1}$) [$2162 \leq Q \leq 2422$]

L = Sprinkler height (cm) [$100 \leq L \leq 140$ cm]

N = Sprinkler Nozzle diameter (mm) [$3.2 \leq N \leq 3.9$ mm]

CONCLUSION

The study results concluded that, there is a significant response between (Yield), AGDD, Sprinkler height (L), water quantity (Q) and Sprinkler Nozzle diameter (N) with R^2 more than 0.90.

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الملخص العربي

تأثير معايير تصميم الرشاشات وموعد الزراعة على الإجهاد الحراري وإنتاجية محصول الدخن

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الدخن هو عشب C4 ينمو في الموسم الدافئ ويتكيف بشكل جيد مع المناخات شبه القاحلة حيث تدفع المخاوف بشأن ندرة الموارد المائية واستنفادها باستمرار إلى البحث عن إدارة محاصيل فعالة في استخدام المياه لتحسين كفاءة استخدام المياه (WUE). أجريت تجربة حقلية في موسم النمو ٢٠٢٣ في محطة بحوث مريوط، مركز بحوث الصحراء، مصر، لتقييم تأثير معايير تصميم الرشاشات وموعد الزراعة على الإجهاد الحراري وإنتاجية محصول الدخن. زرعت التجربة ببذور الدخن في تاريخين. الأول كان ٢٥ يونيو (S1) والثاني كان ١٠ يوليو (S2). تمت مقارنة قطري فوهتين ٣,٢ مم و ٣,٩ مم تحت ثلاثة ارتفاعات مختلفة للرافعة ١,٠ م و ١,٢٠ م و ١,٤٠ م لدراسة تأثير ارتفاع الرشاش وقطر الفوهة في التاريخين المختلفين (S1، S2) على الكتلة الحيوية لمحصول الدخن. يوصى باستخدام هذا التمثيل النموذجي التخطيطي لمفهوم النظام، والذي يمثل سلوك النظام. هناك استجابة كبيرة بين (العائد)، AGDD، ارتفاع الرشاش (L)، كمية المياه (Q) وقطر فوهة الرشاش (N) مع R^2 أكبر من ٠,٩٠.

الكلمات المفتاحية: الري بالرش؛ محصول الدخن؛ موعد الزراعة، الوحدات الحرارية، الإنتاجية.