Maximizing Water Use Efficiency of Pearl Millet by Water and Drip Irrigation Management

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Abstract

The present study was carried out in Marriott Research station of Desert Research Center during summer season 2000 / 2001 to study the effect of five water quantities and three water distribution patterns on water use efficiency, water economy and crop response factor of two pearl millet varieties, i.e., Egyptian (pennisetum glaucum) and Sudanese (pennisetum typhoid).

The highest actual consumptive use value was obtained for Egyptian pearl millet variety at all growth stages. The seasonal water consumptive use of Sudanese pearl millet variety decreased by 55.40 m^3/hectare than Egyptian one. Also, water consumptive use of all growth stages show slightly increases with increasing the number of drippers/m^2 and with the applied irrigation water.

Sudanese pearl millet grains have more water use efficiency (5.60 Kg/m^3) than the Egyptian one (5.37 Kg/m^3). While water use efficiency by fresh and dry weights increased with Egyptian variety. The maximum relative increase in WUE by grain, total fresh, total dry and plant component (stem, leaves and panicles) were achieved by using P3 pattern to applied irrigation water. Also, the WUE increase gradually as applied water depth increase.

With using optimum management, it can be increase the water use efficiency by Egyptian grain variety by 1310 % (relative to Q1P1 treatment) and save 40 % (2073.00 m^3/hectare) of applied water quantity. This result can be achieved by adding 518.25 mm (Q3) calculated from the Penman-Montieth model multiplied by 1.0 and distributed by the narrow pattern (P3). Moreover, this treatment produces 58.03 ton/hectare of Egyptian grains with 3.03 ton/hectare (4.96 %) decrease, comparing to applying Q5 dose.

Keywords: Pearl millet, varieties, water quantities, Penman – Montieth, water distribution patterns, water management, yield, drip irrigation, Water use efficiency, crop response factor.

Introduction

For many years, the emphasis of sustainable irrigated agriculture has been on improving the effectiveness of water management and water conservation. Micro-irrigation system is one of the technologies which offer many unique agronomic, water conservation and economic advantages need to address the challenges for irrigated agriculture in the future.

With the present emphasis on improving the efficiency of irrigation water use, there is a need to develop technical skills, which are necessary to apply water efficiently. Irrigation water management remains the main factor affecting irrigation performance, regardless of irrigation method.

More efficient trickle irrigation application methods are needed for good water management. Consequently, advance rates are very sensitive to the applicable quantities and drippers' distribution patterns so that as trickle reduces the infiltration, the hydraulic performance for the irrigation system improved by a process of intermittently applying water in a certain quantities.

Kirda (2000) stated that it is necessary to develop new irrigation scheduling approaches, not necessary based on full crop water requirement, but ones designed to ensure the optimal use of allocated water. The aim of this work is to study the effect of applied water quantity and water distribution pattern on water consumptive use, optimum water use efficiency of two pearl millet varieties grown on calcareous soil.

Materials and methods

This study was carried out in Maryuot Agricultural Research Station; South – West of Alexandria during summer 2001 season. The study is conducted to evaluate the influence of the applied water depth and water distribution uniformity of trickle irrigation system on consumptive use, water use efficiency, water economy and crop response factor by the two pearl millet varieties under calcareous soil conditions.

Data revealed that the soil is Loamy-textured with sandy loam at surface (0 - 20 cm) and deepest (80 - 100 cm) layers. The total carbonate content increased with depth and ranged from 28.5 % to 30.1 %. Also, the soil bulk density increased with depth and varied between 1.42 and 1.57 g/cm3. Soil pH ranged from 7.5 to 7.7. Electrical conductivity of soil paste indicates that soil is slightly saline, where ECe values varied from 2.8 (at 40 - 60 cm depth) to 3.9 dSm^{-1} at the surface layer. The soil saturation extract showed that Na^{+} and Ca^{++} were the dominant cationic composition while Cl^{-} was the dominant anion followed by $SO4^{--}$ and HCO^{-}.

The experiment was arranged in split – split plot design with four replicates. Each of plots was bounded by 1.5 m wide levees to avoid horizontal water movement. The main plots were planted in 4/5/2001 at the rate of 16.7 Kg/ha. with two pearl millet varieties, i.e., Egyptian (*pennisetum glaucum*) or Sudanese pearl millet (*pennisetum typhoidum*).The sub-main plots were irrigated by five water quantities (ETm) which obtained from the product of the reference evapotranspiration (ETo) calculated by using Penman-Montieth equation multiplied by crop coefficient for every stage (according to Allen et al 1998) multiplied by a factors as follow: Q1 = ETo × KC × 0.6, Q2 = ETo × KC × 0.8, Q3 = ETo × KC × 1.0, Q4 = ETo × KC × 1.2 and Q5 = ETo × KC × 1.4.

The sub– sub main treatment was water distribution pattern, which differs as number of drippers differs. Three water distribution patterns as follows: P1 = one dripper (4L / h) per $0.6m^2$ (10 drippers / plot), P2 = one dripper (4 L / h) per $0.3m^2$ (20 drippers / plot) and P3 = one dripper (4L / h) per $0.2m^2$ (30 drippers / plot), Fig. (1). All experimental plots were irrigated every day by Q3 quantity for twenty days after planting, then water doses were added every two days.

CropWat 4 Windows (version 3.4), Smith (1991) software program provided by FAO was used to calculate the reference evapotranspiration using the mean of 30 years meteorological data.

All plots were fertilized by 357 kg/ha calcium superphosphate before planting, 190.5 kg /ha ammonium sulfate and 79.8 kg /ha potassium sulfate during the vegetative growth stage in liquid form by injection in irrigation water.

The average soil moisture content was determined gravimetrically for the 0-100 cm depth at all plots immediately before and after 24 hours from irrigation. Actual evapotranspiration was calculated for the various plant growth stages and for the total season using the estimated average soil moisture content. Crop coefficient was calculated according to Yaron et al (1973). Water use efficiency (Kg/m^3) was calculated according to Giriappa (1983).

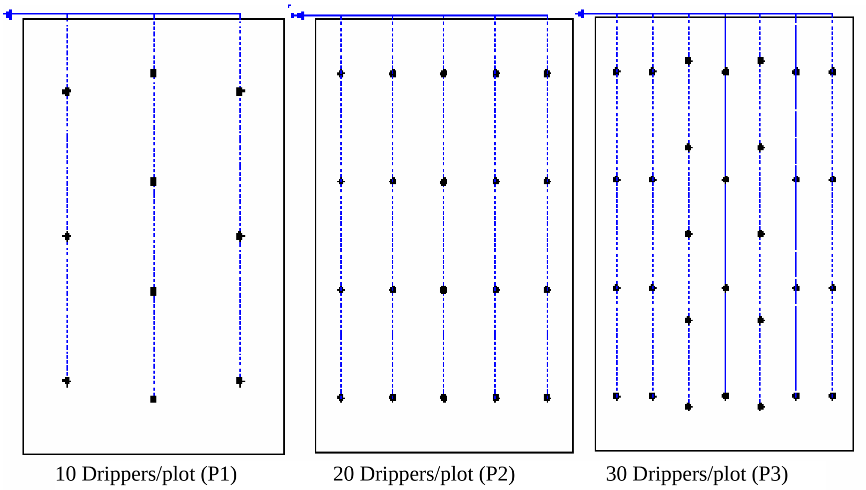

Fig. (1): The layout of water distribution patterns (P1, P2 and P3).

Results and Discussion

The effect of studied treatments on consumptive use

Figure (2) shows the values of the daily reference evapotranspiration, which revealed that the highest value of ETo (6.11 mm/day) was obtained in July month, then the values decreased through the period of study to reach 3.83 mm/day in October month. These values may be attributed to the meteorological data of this period of the year.

Moreover, Fig. (3) illustrate the growth periods (day) of the pearl millet crop, i.e., initial [I], vegetative [II], mid-season [III] and late-season stages [IV] and total pearl millet growth season. It also showed the crop coefficient (Kc) for different growth stages. It clearly shows that mid-season stage is the longest stage period (55 days) and the crop coefficient reaches its maximum value (1.00) at this stage.

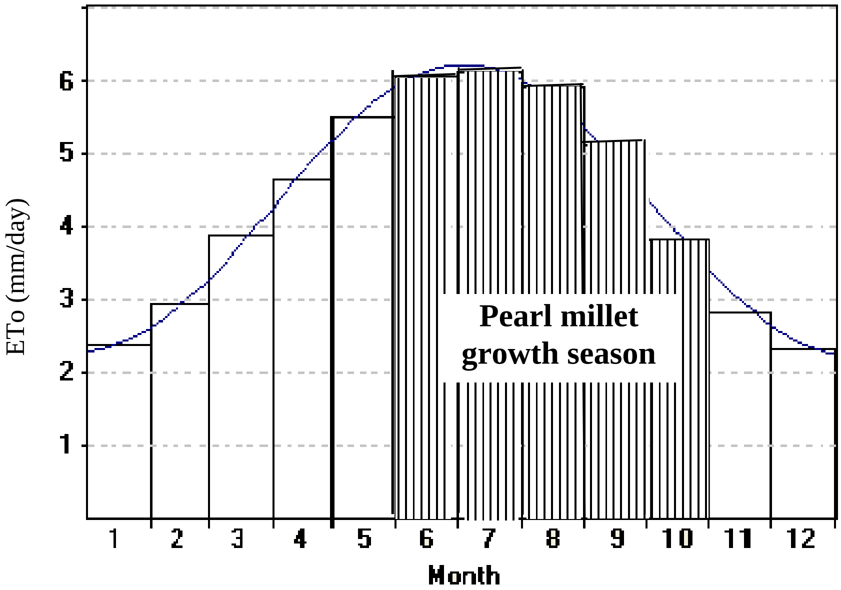

Fig. (2): Reference evapotranspiration (mm/day) through pearl millet growth period.

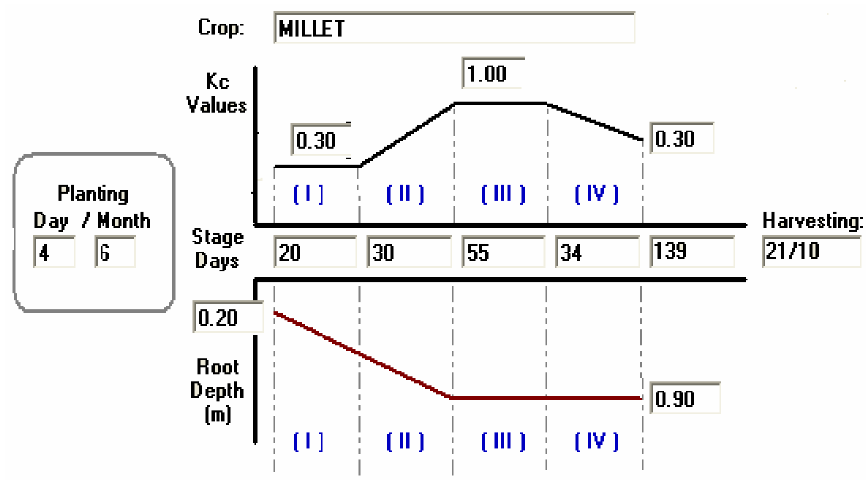

Fig. (3): Crop coefficient (Kc) and periods (day) of pearl millet growth stages.

Regarding to the five water quantities (ETm), mm, which were applied for every stage, data in Table (1) show that the highest water amount was applied through the mid-season stage, representing 59.4 % of the seasonal applied water quantity. On the other hand, the water amount that added at initial, development and late-season stages represent 7.0%, 22.80% and 10.80% of the seasonal water quantity, respectively.

1- Effect of crop variety on water consumptive use

Concerning the effect of pearl millet varieties, Table (2), it was found that the highest actual consumptive use value was obtained for Egyptian pearl millet variety at all growth stages. The seasonal water consumptive use of Sudanese pearl millet variety decreased by 55.40 m^3/hectare than Egyptian one.

Table (1): The applied water quantities (mm) for every stage and total pearl millet growth season.

Applied water depth	Stages								Seasonal	
	Initial		Development		Mid-season		Late-season			
	from	to	from	to	from	to	from	to	from	to
	4 / 6	23 / 6	24 / 6	23 / 7	24/ 7	16/ 9	17/ 9	21/ 10	4 / 6	21/ 10
Q1	21.78		71.04		184.68		33.45		310.95	
Q2	29.04		94.72		246.24		44.60		414.60	
Q3	36.30		118.40		307.80		55.75		518.25	
Q4	43.56		142.08		369.36		66.90		621.90	
Q5	50.82		165.76		430.92		78.05		725.55	

Table (2): Actual consumptive use (mm) of pearl millet as affected by varieties.

Variety	Stages				Seasonal
	Initial	Development	Mid season	Late season	
Egyptian	34.45	110.75	284.23	49.80	479.22
Sudanese	33.97	109.66	281.50	48.55	473.68

2- Effect of water distribution patterns on water consumptive use

Regarding the effect of water distribution patterns, data in Table (3) reveal that water consumptive use of all growth stages show slightly increases with increasing the number of drippers/m2. These increases might be due to the increasing in the wet surface area with increasing the number of drippers and causing higher evaporation, Gaber (1993).

Table (3): Actual consumptive use (mm) of pearl millet as affected by water distribution patterns.

Water distribution patterns	Stages				Seasonal
	Initial	Development	Mid season	Late season	
P1	33.24	109.15	280.66	47.98	481.04
P2	34.42	110.19	282.92	48.90	496.43
P3	34.97	111.28	285.01	50.64	511.89

3- Effect of applied depth of irrigation on water consumptive use

Data of actual consumptive use values as affected by applied water quantities are presented in Table (4). Increasing the applied irrigation water generally increased the water consumptive by pearl millet plants for every stage and total season. Also, under all applied water depths, the data show that the highest actual evapotranspiration (ETa) was obtained at the mid-season which represented about 60 % of the seasonal ETa, followed by the values obtained at development stage (about 23 % of the seasonal

ETa). While the lowest ETa was obtained at initial stage, which represent about 7 % of the seasonal ETa.

The maximum response to applied water quantities was observed under Q2 (ETo × KC × 0.8) treatment, where the seasonal actual consumptive use by pearl millet that irrigated with Q2 amount was 97.70 % of the applied water. On the other hand, the minimum response to applied water quantities was found under Q5 (ETo × KC × 1.4) treatment, where pearl millet that irrigated with Q5 amount consumed 84.09 % of the applied water. These results are in agreement with those obtained by Gaber and El-Dosouky (1992), El-Dosouky and Gaber (1994) and Gaber (2000). They stated that the consumptive use (ETa) vales of barley at vegetative and flowering stages were higher than at yield formation and ripening stages, where barley needs from 59 to 67 % of its water requirements during the late vegetative and flowering stages.

Table (4): Actual consumptive use (mm) of pearl millet as affected by applied water quantities.

Applied water quantities	Stages				Seasonal
	Initial	Development	Mid season	Late season	
Q1	20.81	70.39	180.64	31.49	303.31
Q2	28.53	92.63	244.44	39.44	405.05
Q3	35.82	117.36	298.81	54.10	506.09
Q4	41.57	129.09	331.56	55.44	557.67
Q5	44.32	141.56	358.87	65.40	610.15

4- Effect of crop variety and water distribution pattern on water consumptive use

The actual evapotranspiration (ETa) for every stage and over the total season was generally increased by increasing the number of drippers which were used to applying irrigation water under both varieties (Table 5). Also, data show that increasing the number of drippers from P1 to P2 (dripper/0.3m2) has more effect on ETa at all growth stages for Sudanese variety while increasing the number of drippers from P2 to P3 has more effect on ETa at all growth stages for Egyptian variety.

Table (5): Actual consumptive use (mm) of pearl millet as affected by crop varieties and water distribution pattern.

Treatments		Stages				Seasonal
Crop variety	Water distribution patterns	Initial	Development	Mid season	Late season	
Egyptian	P1	33.58	109.73	282.47	48.58	474.36
	P2	34.62	110.61	283.85	49.38	478.46
	P3	35.17	111.90	286.35	51.42	484.85
Sudanese	P1	32.91	108.57	278.86	47.39	467.72
	P2	34.22	109.76	281.98	48.42	474.39
	P3	34.77	110.65	283.67	49.85	478.94

5- Effect of crop varieties and applied water quantities on water consumptive use

Increasing the applied irrigation water generally increased the water consumptive by the two varieties for every stage and total season, Table (6). Also, under all applied water depths, the data show that there are very slightly differences between the two varieties in their actual evapotranspiration at all growth stages and through the total season. The highest difference was found under applying the maximum depth of water to irrigate Sudanese variety, which consumed water less by 17.32 m3 / hectare compared to Egyptian one.

Table (6): Actual consumptive use (mm) of pearl millet as affected by crop varieties and applied water quantities.

Treatments		Stages				Seasonal
Crop varieties	Applied water quantities	Initial	Development	Mid season	Late season	
Egyptian	Q1	20.88	70.43	181.33	31.74	304.38
	Q2	28.61	93.14	245.36	40.03	407.14
	Q3	35.92	117.57	300.43	54.55	508.47
	Q4	41.87	130.13	332.70	56.04	560.74
	Q5	44.99	142.47	361.31	66.61	615.39
Sudanese	Q1	20.73	70.34	179.94	31.23	302.24
	Q2	28.46	92.12	243.53	38.85	402.96
	Q3	35.72	117.15	297.20	53.65	503.71
	Q4	41.27	128.06	330.43	54.83	554.59
	Q5	43.65	140.64	356.43	64.19	604.91

6- Effect of water distribution patterns and applied water quantities on water consumptive use

The values of actual consumptive use (mm) of pearl millet were generally increased as the applied water amount increased and / or as the number of drippers increased, Table (7). The maximum increasing rate of initial and seasonal ETa was achieved by irrigating with Q2 dose (ETo × KC × 0.8) which was distributed by P2 (dripper/0.3m2). Such increase reached 39.58 and 33.31 % relative to applying Q1 (ETo × KC × 0.6) which was distributed by P2. While the maximum increasing rate of development and mid - season ETa were achieved by irrigating with Q2 dose which was distributed by P1 (dripper/0.6m2). Such increase reached 32.26 and 35.97 % relative to applying Q1 which was distributed by P1 pattern. Also, the maximum increasing rate of late - season ETa was achieved by irrigating with Q3 dose (ETo × KC × 1.0) which was distributed by P1. Such increase reached 39.82 % relative to applying Q2 which was distributed by P1 pattern.

7- Effect of crop varieties, water distribution patterns and applied water quantities on water consumptive use

Data in Table (8) showed that the water consumptive use was gradually increased as plant growth progressed and reached its maximum at mid – season stage. The highest values of ETa at all growth stages were obtained when Egyptian pearl millet irrigated by Q5 dose (ETo × KC × 1.4) using the narrow distribution pattern, P3 (dripper/0.3m2). While the lowest values of ETa were recorded for Sudanese pearl millet irrigated by Q1 dose (ETo × KC × 0.6) using the wide distribution pattern, P1 (dripper/0.6m2). Data also indicated that increasing the applied water quantity, and/or decreasing the space between drippers generally increased the actual evapotranspiration for every stage and over the total season. In addition, the ETa for Egyptian pearl millet was higher compared with Sudanese one. This increase in ETa might be due to the increase in plant growth and transpiration in addition to the higher evaporation from the wet top layer rather than from the dry soil surface. These results are in agreement with the findings of Gaber and El-Dosouky (1992), Gaber (1993), Gaber (2000) and Seidhom (1995) and (2001).

Table (7): Actual consumptive use (mm) of pearl millet as affected by applied water quantities and distribution pattern.

Treatments		Stages				Seasonal
Water distribution patterns	Applied water quantities	Initial	Develo-pment	Mid season	Late season	
P1	Q1	20.34	69.56	179.36	30.40	299.65
	Q2	27.86	92.00	243.87	38.22	401.94
	Q3	35.65	116.79	296.83	53.44	502.70
	Q4	39.37	127.75	328.61	54.36	550.08
	Q5	43.01	139.67	354.66	63.51	600.83
P2	Q1	20.64	70.72	180.98	31.24	303.57
	Q2	28.81	92.55	244.29	39.05	404.69
	Q3	35.80	117.23	297.80	54.11	504.93
	Q4	42.38	129.15	331.64	55.46	558.62
	Q5	44.49	141.29	359.89	64.67	610.33
P3	Q1	21.45	70.88	181.57	32.83	306.72
	Q2	28.93	93.35	245.18	41.07	408.52
	Q3	36.03	118.06	301.81	54.76	510.65
	Q4	42.98	130.38	334.45	56.50	564.30
	Q5	45.47	143.72	362.07	68.04	619.29

The effect of studied treatments on water use efficiency (WUE)

1- Effect of crop variety on water use efficiency

Data in Table (9) show that Sudanese pearl millet grains have relatively more water use efficiency (5.60 Kg/m3) than the Egyptian one (5.37 Kg/m3). Such increase reached 5.59 %. While WUE by fresh and dry weights increased with Egyptian variety. The maximum increases were observed for fresh panicles and dry stem & leaves of Egyptian pear millet. Such increases reached 32.16 and 33.40 %, respectively. The maximum value of WUE was obtained by total fresh weight of Egyptian variety (23.40 kg/m3) with 16.01 % increase relative to Sudanese variety.

It is clear that Egyptian pearl millet variety has a high efficiency to consumptive water for fresh and dry production, while Sudanese variety has a high efficiency to consumptive water for grain production. These results may also be attributed to differences in genetic factors and climatic conditions (Hussein; 1999 and Sedhom; 2001).

Table (8): Actual consumptive use (mm) of pearl millet as affected by crop variety, water distribution patterns and applied water quantities.

Crop varieties	Water distribution patterns	Applied water quantities	Initial	Development	Mid season	Late season	Seasonal
Egyptian	P1	Q1	20.39	69.54	180.21	30.80	300.94
		Q2	27.97	92.42	244.98	38.54	403.91
		Q3	35.74	117.01	297.83	53.86	504.44
		Q4	39.50	128.82	330.34	55.00	553.66
		Q5	44.28	140.88	358.98	64.70	608.84
	P2	Q1	20.68	70.78	181.76	31.42	304.64
		Q2	28.85	92.89	245.12	39.41	406.27
		Q3	35.88	117.58	298.63	54.33	506.42
		Q4	42.87	130.02	332.54	55.91	561.34
		Q5	44.80	141.79	361.22	65.84	613.65
	P3	Q1	21.56	70.98	182.02	33.00	307.56
		Q2	29.00	94.11	245.98	42.14	411.23
		Q3	36.15	118.11	304.82	55.47	514.55
		Q4	43.25	131.54	335.21	57.21	567.21
		Q5	45.89	144.75	363.74	69.30	623.68
Sudanese	P1	Q1	20.28	69.57	178.50	30.00	298.35
		Q2	27.75	91.57	242.75	37.89	399.96
		Q3	35.55	116.56	295.83	53.02	500.96
		Q4	39.23	126.68	326.87	53.71	546.49
		Q5	41.73	138.45	350.33	62.31	592.82
	P2	Q1	20.59	70.66	180.20	31.05	302.50
		Q2	28.77	92.21	243.45	38.68	403.11
		Q3	35.71	116.87	296.97	53.88	503.43
		Q4	41.88	128.28	330.74	55.00	555.90
		Q5	44.17	140.79	358.55	63.50	607.01
	P3	Q1	21.33	70.78	181.12	32.65	305.88
		Q2	28.85	92.58	244.38	39.99	405.80
		Q3	35.90	118.01	298.79	54.05	506.75
		Q4	42.71	129.22	333.68	55.78	561.39
		Q5	45.04	142.68	360.40	66.77	614.89

Table (9): Water use efficiency (kg/m3) of fresh, dry and grain of pearl millet as affected by varieties.

Crop variety	Fresh		Dry			Grain
	Stem & leaves	Panicles	Stem & leaves	Panicles	Total	
Egyptian	16.66	6.74	6.83	5.59	12.42	5.37
Sudanese	15.07	5.10	5.12	5.38	10.50	5.67

2- Effect of water distribution patterns on water use efficiency

The WUE of grain yield values follow the order P3>P2>P1, which means that the efficiency increase by improving the distribution of applied irrigation water, Table (10). The maximum relative increases in WUE by grain was achieved by using P3 pattern to applied irrigation water. Such increase reached 116.16 % relative to that obtained by using P2 pattern, which caused 96.77 % increase relative to that obtained by using P1 pattern.

The same trend was observed for the WUE by total fresh, total dry and plant component (stem, leaves and panicles). The highest values were 31.55 and 17.59 Kg/m3 for the total fresh and total dry pearl millet production, respectively, which was achieved by using P3 pattern to applied irrigation water. The maximum relative increases in WUE by the total fresh and dry pearl millet production and its component were obtained by using P2 pattern to applied irrigation water. For example, such increases reached 107.45 and 91.47 % for total fresh and dry production, respectively, relative to that obtained by using P1 pattern, while using P3 pattern to applying irrigation water caused 53.16 and 78.04 % increases relative to that obtained by using P2 pattern.

3- Effect of applied depth of irrigation water on water use efficiency

The WUE increases gradually as applied water depth increase, Table (11). The highest WUE by grain was belonged to the highest applied water quantity (Q5), 5.80 Kg/m3, which increase by 11.54 % relative to that obtained by applying the lowest water quantity (Q1).

On the other hand, data reveal that water use efficiency by the total fresh, dry and plant component (stem, leaves and panicles) of pearl millet were decreased as applied water depths increased. The highest decrease in WUE by fresh leaves & stem pearl millet associated with applying the highest water dose, Q5 (27.20 %, relative to the value of applying the lowest irrigation water quantity).

Table (10): Water use efficiency (kg/m3) of fresh, dry and grain pearl millet as affected by water distribution patterns.

Water distribution patterns	Fresh			Dry			Grain
	Stem & leaves	Panicles	Total	Stem & leaves	Panicles	Total	
P1	8.28	1.65	9.93	3.53	1.63	5.16	2.17
P2	16.23	4.37	20.60	5.78	4.10	9.88	4.27
P3	20.79	10.76	31.55	7.78	9.80	17.59	9.23

There was exception, which for the WUE by dry leaves & stems pearl millet where it increased gradually by increasing the applied water quantities. The highest WUE by dry leaves & stem pearl millet was obtained by adding the highest irrigation water dose causing an increase reached 17.72 % relative to that obtained with applying the lowest irrigation water depth (Q1).

Table (11): Water use efficiency (kg/m3) of fresh, dry and grain pearl millet as affected by applied water quantities.

Applied water quantities	Fresh			Dry			Grain
	Stem & leaves	Panicles	Total	Stem & leaves	Panicles	Total	
Q1	20.11	6.29	26.41	5.53	5.74	11.27	5.20
Q2	17.18	6.47	23.65	5.95	5.90	11.85	5.43
Q3	14.64	5.66	20.30	5.85	5.33	11.19	5.45
Q4	14.64	5.67	20.31	5.79	5.26	11.05	5.52
Q5	15.03	5.83	20.86	6.51	5.42	11.93	5.80

4- Effect of crop variety and water distribution pattern on water use efficiency:

Data in Table (12) revealed that WUE increased when the distance between drippers decreased at the two varieties. The highest value of WUE by grain was found (10.22 Kg/m3) with the narrow distribution patterns (P3) when used to irrigate the Egyptian pearl millet variety. The latter treatment caused an increase of 6.5 times relative to the value of applying the wide distribution patterns (P1), while the corresponding relative increase in the WUE by Sudanese grain reached 3.3 times only. These results indicated that the grain of Egyptian pearl millet have a higher WUE than Sudanese one by using water distribution management.

Respecting the WUE by total fresh, total dry and plant component (stem, leaves and panicles) of pearl millet, data showed the same trend of grain. For example, the highest values of WUE by total fresh and dry production were obtained when the Egyptian variety irrigated by the narrow water distribution pattern (P3). Such treatment increase WUE for total fresh and dry pearl millet by 3.2 and 3.6 limes relative to the values of Egyptian variety irrigated with the wide distribution pattern (P1).

Table (12): Water use efficiency (kg/m3) of fresh, dry and grain pearl millet as affected by crop varieties and water distribution.

Treatments		Fresh			Dry			Grain
Crop variety	*Water distribution patterns*	Stem & leaves	Panicles	Total	Stem & leaves	Panicles	Total	
Egyptian	*P1*	9.47	1.53	11.00	4.23	1.45	5.68	1.57
	P2	18.40	4.97	23.38	6.98	4.13	11.11	4.21
	P3	21.98	13.57	35.54	9.23	11.08	20.31	10.22
Sudanese	*P1*	7.43	1.83	9.26	2.97	1.88	4.85	2.87
	P2	15.41	4.12	19.53	5.05	4.43	9.48	4.70
	P3	22.20	9.26	31.46	7.30	9.74	17.04	9.38

5- Effect of crop varieties and applied water quantities on water use efficiency:

The highest value of WUE was obtained with Sudanese pearl millet variety when irrigated with the highest applied water quantity (Q5), 6.24 Kg/m3. Such treatment increased WUE by 23.56 % relative to the value of the same variety if irrigated with lowest water dose. This may be due to the increase in Sudanese grain production as mentioned before (4.1.5). Moreover the highest value of Egyptian grain variety, 5.53 Kg/m3, was achieved by applying (Q3) water quantity.

With respect to the water use efficiency by total fresh, dry and their components, data indicate that WUE by fresh and dry pearl millet decreased with increasing applied irrigation water under two crop varieties conditions. The highest values (27.58 and 12.88 Kg/m3 for total fresh and dry Egyptian variety) were attained by applying 310.95 mm (Q1) calculated from the Penman-Montieth model multiplied by 0.6. This increase in WUE is due to: i) the decrease of actual evapotranspiration at low applied water quantities, ii) the corresponded high yields. These results are in agreement with the findings of Spigel (1965); Hussein (1999) and Sedhom (2001).

Table (13): Water use efficiency (kg/m3) of fresh, dry and grain pearl millet as affected by crop varieties and applied water quantities.

Treatments		Fresh			Dry			Grain
Crop variety	Applied water quantities	Stem & leaves	Panicles	Total	Stem & leaves	Panicles	Total	
Egyptian	Q1	19.96	7.62	27.58	6.90	5.98	12.88	5.35
	Q2	18.44	7.60	26.04	7.00	5.78	12.78	5.13
	Q3	15.44	6.33	21.77	6.56	5.32	11.88	5.53
	Q4	15.32	6.40	21.72	6.57	5.36	11.93	5.40
	Q5	16.08	6.37	22.45	7.15	5.70	12.84	5.38
Sudanese	Q1	20.27	4.96	25.22	4.15	5.51	9.65	5.05
	Q2	15.90	5.32	21.23	4.89	6.01	10.90	5.74
	Q3	13.83	4.98	18.81	5.14	5.35	10.48	5.37
	Q4	13.96	4.93	18.88	5.00	5.16	10.16	5.63
	Q5	13.97	5.28	19.25	5.87	5.13	11.00	6.24

6- Effect of water distribution patterns and applied water quantities on water use efficiency:

Table (14) show that the values of WUE were gradually increased as applied water depth increased when added by wide distribution pattern (P1). While such values were decreased with increasing the applied water depth when using moderate or narrow distribution patterns (P2 or P3).

The highest value of WUE by grain (10.35 Kg/m3) was obtained by applying 518.25 mm (Q3) calculated from the Penman-Montieth model multiplied by 1.0 and distributed by the narrow pattern (P3), causing an 13.6 times increase relative to adding

Table (14): Water use efficiency (kg/m3) of fresh, dry and grain pearl millet as affected by water distribution patterns and applied water quantities.

Treatments		Fresh			Dry			Grain
Water distribution patterns	Applied Water quantities	Stem & Leaves	Panicles	Total	Stem & Leaves	Panicles	Total	
P1	Q1	5.11	0.93	6.04	1.64	0.81	2.45	0.76
	Q2	6.59	1.50	8.09	2.55	1.47	4.02	1.86
	Q3	6.62	1.38	8.00	2.80	1.42	4.22	1.69
	Q4	9.27	1.85	11.12	3.62	1.69	5.32	2.27
	Q5	11.30	2.12	13.42	5.66	2.27	7.93	3.44
P2	Q1	23.57	4.93	28.50	6.89	5.39	12.27	5.83
	Q2	18.98	4.67	23.65	5.79	4.82	10.61	4.77
	Q3	15.74	3.95	19.69	6.08	4.07	10.15	4.23
	Q4	14.93	4.29	19.22	5.72	3.78	9.50	4.12
	Q5	15.01	5.01	20.02	5.98	3.99	9.97	4.05
P3	Q1	29.65	12.57	42.21	7.44	10.65	18.09	8.65
	Q2	25.82	13.14	38.96	9.45	11.33	20.78	9.59
	Q3	21.45	11.56	33.00	8.63	10.44	19.07	10.35
	Q4	19.60	10.75	30.34	7.97	10.19	18.17	10.07
	Q5	18.68	10.24	28.92	7.88	9.87	17.75	9.82

310.95 mm (Q1) calculated from the Penman-Montieth model multiplied by 0.6 and distributed by the wide pattern (P1).

The highest values of WUE by total dry yield (20.78 Kg/m3) was attained by applying 414.60 mm (Q2) calculated from the Penman-Montieth model multiplied by 0.8 and distributed by the narrow pattern (P3), causing 8.5 times increase relative to adding 310.95 mm (Q1) calculated from the Penman-Montieth model multiplied by 0.6 and distributed by the wide pattern (P1).

7- Effect of crop variety, water distribution patterns and applied water quantities on water use efficiency:

Data in Table (15) show the effect among crop varieties, water distribution patterns and applied water quantities on WUE by pearl millet. Generally, data revealed that WUE values by fresh and dry yield of Egyptian variety of pearl millet were higher compared to Sudanese one under all applied water treatments and water distribution patterns. With using optimum management (Q3P3), it can increase the WUE by grain of Egyptian variety by 14.3 times (relative to Q1P1 treatment) and save 40 % (2073.00 m3/hectare) of applied water quantity. This result can be achieved by adding 518.25 mm (Q3) calculated from the Penman-Montieth model multiplied by 1.0 and distributed by the narrow pattern (P3). Moreover, this treatment produces 58.03 ton/hectare of Egyptian grains with 3.03 ton/hectare (4.96 %) decrease, compared to applying Q5 dose.

Regarding the total fresh yield of pearl millet, Table (15) showed that the maximum WUE value (43.14) was associated with applying 310.95 mm (Q1) calculated from the Penman-Montieth model multiplied by 0.6 which was distributed by the narrow pattern (P3) to irrigate Egyptian variety. Such management increase WUE by 428.03 % and increases the corresponding fresh yield by 453.76 % compared to applying 518.25 mm (Q1) calculated from the Penman-Montieth model multiplied by 0.8 which was distributed by the wide pattern (P1) to irrigate Sudanese variety. This treatment yielded 132.68 ton/hectare and saved 414.60 mm (4146.00 m3/hectare) relative to adding the maximum water amount (Q5) with 30.37 % decrease in total fresh yield, but the water amount which saved can produce 176.91 tons of fresh weight of pearl millet when used to irrigate more area.

With regard to total dry yield of pearl millet, the maximum WUE value (22.80) was associated with applying 414.60 mm (Q2) calculated from the Penman-Montieth model multiplied by 0.8 and distributed by the narrow pattern (P3), causing 458.82 % increase relative to adding 310.95 mm (Q1) calculated from the Penman-Montieth model multiplied by 0.6 and distributed by the wide pattern (P1). This treatment yielded 93.74 ton/hectare and saved 310.95 mm (3109.50 m3/hectare) relative to adding the maximum water amount (Q5) with 26.09 tons decrease in total dry weight, but the water amount which was saved can produce 70.31 tons of fresh weight of pearl millet when used to irrigate more area.

Table (15): Water use efficiency (kg/m3) of fresh, dry and grain pearl millet as affected by varieties, water distribution patterns and applied water quantities.

Treatments			Fresh weight			Dry weight			Grain yield
Crop	Water distribution patterns	Applied water quantities	Stem & Leaves	Panicles	Total	Stem & Leaves	Panicles	Total	
Egyptian	P_1	Q_1	6.92	1.25	8.17	3.01	1.07	4.08	0.80
		Q_2	7.20	1.26	8.46	2.64	1.08	3.72	1.13
		Q_3	6.84	1.25	8.10	3.37	1.19	4.55	1.23
		Q_4	9.69	1.67	11.36	4.53	1.56	6.09	1.77
		Q_5	14.19	1.96	16.15	6.31	2.02	8.33	2.36
	P_2	Q_1	26.34	4.70	31.05	8.60	4.84	13.44	5.53
		Q_2	21.83	4.94	26.77	7.17	4.48	11.65	4.46
		Q_3	17.65	4.32	21.98	6.78	3.98	10.76	3.96
		Q_4	16.12	5.09	21.22	6.41	3.63	10.04	3.88
		Q_5	14.91	5.56	20.46	6.74	4.11	10.85	3.89
	P_3	Q_1	26.40	16.74	43.14	9.01	11.93	20.94	9.60
		Q_2	26.13	16.47	42.60	11.11	11.69	22.80	9.71
		Q_3	21.70	13.27	34.97	9.48	10.69	20.17	11.28
		Q_4	20.01	12.31	32.31	8.72	10.77	19.49	10.45
		Q_5	19.08	11.48	30.55	8.36	10.85	19.21	9.79
Sudanese	P_1	Q_1	6.78	1.25	8.03	1.38	1.11	2.48	1.25
		Q_2	5.97	1.74	7.71	2.46	1.86	4.32	2.61
		Q_3	6.40	1.51	7.90	2.23	1.66	3.88	2.16
		Q_4	8.83	2.03	10.87	2.70	1.83	4.53	2.78
		Q_5	8.32	2.29	10.61	4.98	2.53	7.51	4.55
	P_2	Q_1	20.78	5.16	25.94	5.16	5.94	11.10	6.13
		Q_2	16.10	4.40	20.51	4.40	5.15	9.55	5.08
		Q_3	13.82	3.58	17.40	5.38	4.15	9.52	4.50
		Q_4	13.72	3.49	17.21	5.02	3.94	8.95	4.36
		Q_5	15.11	4.45	19.56	5.20	3.87	9.07	4.22
	P_3	Q_1	32.91	8.37	41.27	5.86	9.36	15.22	7.69
		Q_2	25.50	9.77	35.27	7.77	10.96	18.73	9.47
		Q_3	21.19	9.81	31.00	7.77	10.18	17.96	9.40
		Q_4	19.18	9.17	28.35	7.21	9.61	16.82	9.68
		Q_5	18.28	8.99	27.27	7.39	8.87	16.26	9.85

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تعظيم كفاءة الإستهلاك المائى لمحصول الدخن بإدارة المياه والرى بالتنقيط

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أقيمت تجربة حقلية بمحطة بحوث مريوط التابعة لمركز بحوث الصحراء خلال الموسم الصيفى 2001/2000 لدراسة تأثير خمسة كميات من مياه الرى (60 ، 80 ، 100 ، 120 ، 140 % من تلك المحسوبة طبقا لمعدلة بنمان – مونتيث) بالإضافة إلى ثلاث نظم من توزيع مياه الرى المضافة بإستخدام نظام الرى بالتنقيط (نقاط لكل من 0.2 ، 0.3 ، 0.6 م^2) وذلك على الإستهلاك المائى وكفاءة إستهلاك المياه بمحصول الدخن المصرى والسوداني. وأوضحت النتائج ما يلى :

* سجل محصول الدخن المصري أعلى استهلاك مائي فعلى في كل مراحل نموه ووجد أن الاستهلاك الموسمي للدخن السوداني قد انخفض بمقدار 55.4م^3 / هكتار مقارنة بالدخن المصري . كما أظهرت النتائج زيادة طفيفة عند زيادة عدد النقاطات وزيادة كميات المياه المضافة.
* ازداد الاستهلاك المائي تدريجيا بزيادة مراحل النمو ووصل أقصاه في المرحلة المتوسطة من عمر النبات وكانت أعلى زيادة عند ري الدخن المصري بأعلى كميه للمياه Q5 (ETo × Kc ×1.4) وباستخدام نمط التوزيع P3 (نقاط / 0.2 م^2) بينما كانت اقل القيم كانت عند ري الدخن السوداني بأقل كمية للمياه Q1 (ETo × Kc × 0.6) وباستخدام نمط التوزيع P1 (نقاط / 0.6م^2).
* سجلت حبوب الدخن السوداني أعلى كفاءة إستهلاك للمياه (5.6كجم / م^3) وأكبر من الصنف المصري (5.37 كجم / م^3) بينما إزدادت كفاءة إستهلاك المياه للوزن الطازج و الوزن الجاف للدخن المصري. وكانت أعلى زيادة نسبية لكفاءة إستهلاك المياه للحبوب و الوزن الكلى الطازج و الجاف و مكونات المحصول (سيقان، أوراق، ثمار) مع استخدام توزيع المياه المتقارب P3 للرى ، وعلى سبيل المثال : كانت الزيادة 107.45 ، 91.47 % لكلا من الوزن الطازج و الوزن الجاف بالمقارنة عند استخدام نمط توزيع مياه P1 وكذلك ازدادت كفاءة إستهلاك المياه تدريجيا بزيادة كميات المياه المضافة عند الري.
* باستخدام الإدارة المثلى للمياه يمكن زيادة كفاءة استهلاك المياه للحبوب في صنف الدخن المصري بنسبة 1310% بالنسبة للمعاملة Q1P1 وتوفير حوالي 40% (2073 م^3 / هكتار) من مياه الري المضافة . ويمكن تحقيق ذلك بإضافة 518.25 مم (Q3) المحسوبة من نموذج بنمان – مونتيث مضروبة في واحد

صحيح وتوزيع مياه بنمط (P2) ، وهذه المعاملة تنتج 58.03 طن / هكتار من الحبوب الدخن المصري بنقص يصل إلى 3.03 طن / هكتار (4.96%) بالمقارنة عند إضافة أقصي كميه مياه ري (Q 5).

* كانت أقصى قيم كفاءة لإستهلاك المياه (5.6كجم / م^3) ترتبط بكمية مياه ري 310.95 مم Q1 المحسوبة من نموذج بنمان – مونتيث مضروبة في 0.8 و التي يتم توزيعها بنمط P3 لرى الدخن المصري ، مثل هـــذه الإدارة تزيد كفاءة إستهلاك المياه بمقدار 428.03 % ويزيد المحصول الطازج بنسبة 453.76 % بالمقارنـــة بإضـــافة (310.95(Q1 مم والمحسوبة من نموذج بنمان – مونتيث مضروبة في 0.8 وتوزيع ميـــاه (P1) لـــرى الـــدخن السوداني. وهذه المعاملة تنتج 132.68 طن / هكتار و توفر 414.60 مم (4146 م^3 / هكتار) بالنسبة لإضـــافة أقصى كمية مياه ري Q5 بنقص مقداره 30.37 % في الوزن الطازج ولكن كميه المياه المتوفرة يمكن أن تنـــتج 176.91 طن وزن طازج من الدخن عند ري مساحة اكبر.