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Impact of Irrigation Water Quantities and Soil Mulching on Pearl Millet Performance under Heat Stress Conditions

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DROUGHT and heat stress are considered the most abiotic stresses that affecting crop production in desert areas. Accordingly, two field trials during the 2019 and 2020 were performed at the Agricultural Experiment Station of Desert Research Center, EL-Kharga Oasis, New Valley Governorate, Egypt, to investigate the response of pearl millet to three irrigation levels (100, 75, and 50 % of the water requirement) and five rates of soil mulch (0, 2.4, 4.8, 7.2 and 9.5ton ha^{-1}) under predominant water-scarce and heat stress conditions. The findings showed that pearl millet yields and their traits, as well as grain protein content and water use efficiency (WUE), were significantly affected by mulching, irrigation levels, and their interaction in both seasons. Soil mulching by 9.5ton ha^{-1} gave the highest values for plant height, panicle length, and WUE as compared with un-mulching in both seasons. Whereas, the highest values of grains number/panicle, grain weight/panicle, seed index, biological and grain yields as well as grain protein content were recorded with mulching by 7.2ton ha^{-1} as compared to un-mulching in both seasons. Fully irrigated pearl millet recorded the highest values for all the studied attributes, except WUE, but statistically at par with 75% of the water requirement and each of was over 50% of the water requirement in both seasons. It can be inferred that adding 7.2ton ha^{-1} soil mulch and 75% of the water requirement may be the optimal practice to improve the productivity of pearl millet in hyper-arid areas.

Keywords: Heat stress, Irrigation, Mulching, Pearl millet, Yield and its traits.

Introduction

There is a persistent need to increase the productivity of cereal crops in Egypt nowadays to confront the population increase under water-scarce conditions and climate change patterns, as well as the rapid increase in the saline and infertile soil. In Egypt, pearl millet is primarily grown as a feed crop in summer, while it is the staple grain crop in many countries in Africa and Asia (Reiad et al., 2014). In this regard, the risk factor can be minimized by in-situ moisture management and the selection of the appropriate crop (Kumar et al., 2008). Pearl millet is a well-adapted crop to water scarcity, climate change, increased salinity, drought, infertile soils, and land degradation (Salem, 2020). Also, in underwater stress, many researchers confirmed that the crop may contribute to combating poverty and food insecurity in marginal environments (Shivhare & Lata, 2017; Ullah et al., 2017; Kadivala et al., 2019; Salem, 2020).

One of the most vulnerable is the Western Desert, which occupies about two-thirds of the territory of the country, with harsh plant growth conditions due to hot summers and extreme daily winter temperature variations, as well as rare rainwater. The two major environmental factors restricting crop growth and yield are known to be drought and heat stress, as seen in many crops (Javed & Khalid, 2009). In various cellular and entire plant processes, these two stresses cause many biochemical, molecular, and physiological changes and reactions that impact crop yield and quality (Prasad et al., 2008). Besides, date palm pruning wastes could be a major issue in the New Valley Governorate, Egypt, and affects the

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environment, since farmers burn them in the open field, causing severe air pollution. Where there is an enormous waste of date palm residues, and its effect on the environment has been given little to no attention. A more important problem is that there is no deliberate effort to use the wastes of date palm clipping efficiently, or at least to safely dispose of it. Furthermore, groundwater represents the sole source of water supply in the hyper-arid Kharga oasis and is unsustainably used in the Western Desert. In addition, the Kharga oasis is severely affected by desertification and soil erosion.

Mulching is an effective approach to manage the crop-growing environment by regulating soil temperature, maintaining soil moisture, and reducing soil evaporation to increase crop yield and improve product quality (Chakraborty et al., 2008). Besides, mulching with plant residues has been considered one of the most effective in reducing soil erosion rates and water losses in agricultural lands (Sadeghi et al., 2015; Prosdocimi et al., 2016). Furthermore, soil mulching with plant waste was described by Abouziena & Radwan (2015) and Dong et al. (2009) as one of the best management practices for controlling soil evaporation, improving soil humidity retention, and improving water use efficiency. Also, mulching reduces weed growth and competition from the surrounding fields for water and nutrients, holding the underlying root zone warmer in winter and cooler in summer to reduce root damage, reducing soil pH to improve the ability of crop roots to absorb nutrients and increase. Moreover, the availability of long-term nutrients in the soil, and soil microorganisms are enabled by mulching (Kader et al., 2017). The effect of mulching on moisture conservation and crop productivity improvement was recorded in maize (Zhang et al., 2005), and wheat (Li et al., 2005; Rahman et al., 2005). Uwahm & Iwo (2011), studied the use of 5 organic mulch rates (0, 2, 4, 6, and 8ton/ha) on maize productivity, they found that soil moisture reserves, plant height, and a number of leaves/plant were the highest at the mulch rate of 8ton/ha, followed by 6 t/ha. While, the un-mulching plots had the lowest soil moisture reserves, smallest plants, and least number of leaves/plants. These above-mentioned findings have clearly shown that the retained moisture by crop residues as mulching has been very successful during stress in plants. In addition, mulching is considered as one of the appropriate methods for preserving optimum soil humidity and thermal conditions, increasing water use efficiency by reducing evaporation and consequently increasing grain yield.

Water, which directly affects plant growth and development, is the main problem of summer cultivation in New Valley since it is the basic input for increasing crop production in semi-arid desert areas. He et al. (2018) reported that the annual crop evapotranspiration (ETc) is much higher than the overall precipitation, and about 50% of the total evapotranspiration occurs through the soil surface. Consequently, urgent attention is needed in the judicial application of water, and this can only be accomplished by pursuing scientific and advanced bases for the application of irrigation water to crops (Shubham et al., 2018). So, Appropriate water-saving initiatives for agriculture need to be developed as an effective measure to achieve relatively stable crop productivity in arid and semi-arid regions with limited water supply. Deficit irrigation (i.e. irrigation below sufficient crop water requirements) is a water-saving technique by which crops are subjected to a certain amount of water stress either at a specific period or during the growing season (Pereira et al., 2002). Additionally, deficit irrigation control is an irrigation method in which a field is irrigated below full crop water requirements to reduce water demand and maximize the efficiency of water usage. For proper growth as well as plant development and for alleviating moisture stress at critical crop growth stages, maintaining optimum moisture at root zone depth is important (Bodner et al., 2015). Among water management practices for increasing water use efficiency, especially on a field scale, the combined practice of deficit irrigation and mulching appears to be very promising (Abd El-Mageed et al., 2016).

Information is insufficient about the effect of mulching and low water supply on the productivity of summer pearl millet. Moreover, the practice of soil mulching is important to preserve underground water that in the study area is depleting at an alarming pace. Considering the above facts in view, the current research carried out with the objectives to study the interactive effect of plant waste mulch and variable irrigation levels on yield and its components, and water use efficiency of pearl millet; and to identify the optimal date palm residues rates as mulching in the hyper-arid Kharga oasis, which suffers from severe depletion in its underground water.

Materials and Methods

The experimental site attributes

Two field experiments were conducted in the Desert Research Center (D.R.C.), Agricultural Experiment Station at EL-Kharga Oasis, New Valley Governorate, Egypt (27°47.7\ 42\\ N and 30°24.7\ 63\\ E), during the two summer growing seasons of 2019 and 2020, to study the response of pearl millet (*Pennisetum glaucum* (L.) R. Br) to irrigation water quantity and application of soil mulching (date palms clipping). The research area is characterized by heat stress conditions without rainwater. The meteorological of the study location data are shown in Table 1. The mechanical and chemical soil properties of the studied site were measured according to Jackson (1973) and recorded in Table 2. Also, the chemical analysis of irrigation water was assessed using the standard method of Page et al. (1982) and presented in Table 3. The preceding crop was faba bean (*Vicia faba* L.) in both seasons.

TABLE 1. Meteorological data during pearl millet growth in 2019 and 2020 seasons

Seasons	Months	Temperature (Average) (°C)		Relative humidity (%)		Average evapo-transpiration reference (mm/day)	Rain mm/month	Wind speed (km/h)
		Max.	Min.	Max.	Min.			
2019	May	45.2	23.6	37.0	21.2	7.5	0.00	33.36
	Jun	43.7	25.8	39.6	25.4	7.8	0.00	31.46
	July	40.1	25.9	41.1	24.5	7.7	0.00	26.74
	August	44.3	27.6	40.8	23.0	7.4	0.00	22.53
2020	May	44.3	23.4	36.2	22.4	7.4	0.00	34.58
	Jun	42.1	25.0	39.0	24.6	7.7	0.00	31.28
	July	41.8	25.2	42.3	23.4	7.8	0.00	27.10
	August	42.9	26.7	41.9	24.1	7.3	0.00	21.53

TABLE 2. The mechanical and chemical properties of the experimental soil

Season	Particles distribution (%)			Texture	EC (ppm)	pH	Available cations					Available anions (meq/L)			
	Sand	Silt	Clay				P ppm	K ppm	Na ppm	Ca meq/l	Mg meq/l	$CO_3^{=}$	Hco_3^{-}	Cl^{-}	So_4^{--}
2019	44.19	21.51	25.54	Sandy clay loam	634	8.74	0.64	31	4.54	7.50	2.79	-	6.11	22.34	7.29
2020	42.15	24.63	26.94		614	8.67	0.69	35	4.15	7.71	3.24	-	5.87	22.62	7.34

TABLE 3. Chemical analysis of irrigation water

Season	pH	E.C. (ds/m)	S.A.R	Soluble cations (meq/L)				Soluble anions (meq/L)			
				Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_{3-}	$SO4^{=}$	Cl^{-}
2019	7.70	1.17	6.58	13.68	2.74	11.82	0.37	-	5.43	4.37	9.47
2020	7.84	1.12	5.14	15.32	2.93	10.51	0.48	-	5.69	4.76	10.24

Experimental design and treatments

The experiment included 15 treatments which were the combinations of three irrigation water amounts and five rates of soil mulching by using the waste of date palm clipping. Irrigation was applied as a ratio of crop evapotranspiration (100, 75, and 50% of the water requirement, which were equivalent to 6000, 4500, and 3000m^3/ha, respectively, as an average for the two seasons). Soil mulching were 0, 2.4, 4.8, 7.2, and 9.5 ton ha^{-1}. The design of the experiment was a strip plots design with three replicates. The experimental plot area was 3.5 m x 3 m. Pearl millet seeds were sown in hills 25 cm apart, on ridges of 60cm width and 3.5m length, and all treatments were separated by 1m as a border.

Irrigation water management

At sowing till germination, water was applied similarly to all irrigation treatments, then irrigation treatments began nine days after full germination. The FAO 56-Penman-Monteith method (equation1) given by Allen et al. (1998) was used to calculate the reference evapotranspiration based on the meteorological data provided in Equation 1 as follows:

$$ET_0= [0.408\ \Delta(R_n - G) + \gamma[900/(T + 273)]U_2 (es- ea)]/ [\Delta + \gamma (1 + 0.34U_2)] \text{......................}(1)$$

where: ET_0 is reference evapotranspiration (mm day^{-1}), R_n is net radiation at the crop surface ([MJ m^{-2} day^{-1}), G is soil heat flux density ([MJ m^{-2} day^{-1}), T is mean daily air temperature at 2m height (°C), U_2 is the wind speed at 2m height (m sec^{-1}), es is saturation vapor pressure (kPa), ea is actual vapor pressure (kPa), es−ea is saturation vapor pressure deficit (kPa), Δ is the slope of vapor pressure curve (kPa °C^{-1}) and γ is psychrometric constant (kPa °C^{-1}).

Evapotranspiration of the Pearl millet crop was calculated based on Equation 2 proposed by Allen et al. (1998):

$$ET_c= K_c \times ET_o \quad \text{……………….} (2)$$

where, ET_c= Daily crop evapotranspiration (mm), K_c= Daily crop coefficient, ET_o = grass reference evapotranspiration (mm)

Water was applied to the upper end of the furrows by PVC gated pipes built in the irrigation channel, which transmit the water at the appropriate flow rate (one gate per furrow). A flow meter installed on the irrigation system supply line measured the quantity of water applied. The amount of water used during each irrigation event was suitable for the growth stage of the crop, as defined by Dorrenbos & Pruitt (1977).

Field management

Shandaweel 1 cultivar of pearl millet was sown on the 1st and 4th of May in both 2019 and 2020, respectively at a rate of 36.0kg/ha. During soil preparation, a mixture of 24m^3/ha chicken manure, 74.0kg P_2O_5/ha, and 119.0 kg K_2O/ha was added. At 21 days after sowing, the plants were thinned to hold one plant per hill. Nitrogen fertilizer at a rate of 179.0kg N/ha as ammonium sulfate was added into two equal doses, at sowing and 25 days after sowing, respectively. The source of irrigation was groundwater and was applied through the gated pipe irrigation system. All agricultural practices for pearl millet were followed according to the recommendation of the Egyptian Ministry of Agriculture throughout the two experimental seasons. Pearl millet plants were harvested when 60 % of panicles were matured on 20 and 25 August in 2019 and 2020, respectively.

Sampling and assessments

Yield traits

At harvest, 10 guarded plants were selected randomly from each plot to measure plant height, panicle length, number of grains/panicle, grain weight/panicle, seed index. In addition, whole plants of the plot were harvested to measure the biological and grain yields/hectare.

Water use efficiency

Water use efficiency (WUE) of pearl millet was computed according to Equation 3 proposed by Payero et al. (2008) as follow:

WUE (kg m^{-3})= [Grain yield (kg $ha^{-1)}$]/ ETc (m^3 ha^{-1})

Grain protein content

Using the modified micro Kjeldahl technique as described in AOAC (2005), total nitrogen was determined in grains. The crude protein content % was calculated by multiplying the total nitrogen % by 6.25.

Statistical analysis

All the obtained data of each season were statistically analyzed using the appropriate analysis of variance in step with Gomez & Gomez (1984), using MSTAT–C software program (MSTATC, Michigan State Univ., 1992). Means were compared by using the least significant difference (LSD) test at P< 0.05.

Results and Discussion

Plant height and yield attributes

Concerning the effect of soil mulching on plant height, panicle length, number of grains/panicle, grains weight/panicle, and seed index, the outcomes in Table 4 demonstrated that all the studied traits were significantly affected by soil mulching in both seasons. In this respect, the addition of 9.5ton ha^{-1} of date palm residues gave the highest values for plant height and panicle length compared with no soil mulch in both seasons. Such superior treatment had an improvement in the previously described characteristics of 39.4 and 43% as well as, 48.4 and 50.0% in 2019 and 2020 seasons, respectively. Whereas, the highest values of the number of grains/panicle, grain weight/panicle, and seed index were recorded with adding 7.2ton ha^{-1} compared to without soil mulch in both 2019 and 2020 seasons. Moreover, such predominant treatment increased each of the numbers of grains/panicle by 25.2 and 24.3%, grains weight/ear by 42.9 and 40.5%, and seed index by 69.8 and 65.2% in 2019 and 2020 seasons, respectively compared to un-mulched soil treatment (Table 4). Such findings are comparable with Eze et al. (2019). In this regard, the mulching with pruning residues has been found to achieve good results in reducing the rate of soil erosion on agricultural land (Cerdà et al., 2016; Liu et al., 2012). The valuable impact of the high mulch application rate on plant height and yield components may increase the rate of water infiltration (Yin Minhua et al., 2018), enhanced the soil ability to hold water, soil structure, and suppress weed growth (Mutetwa & Mtaita, 2014; Nwosisi et al., 2019), and decreased soil temperature (Abouziena & Radwan, 2015). In this context, Zhang et al. (2009) reported a 4˚C decrease in soil temperature during the warmer period and a 2˚C increase in soil temperature during the colder period. Soil mulching also increases the content of organic matter and improves the soil's physical properties (Jordan et al., 2010), which, may also be the reason behind higher nutrient uptake (Eze, 2015). These results have also been recorded by Reiad et al. (2014); Wang & Xing (2016) and Abd El-Mageed et al. (2016).

The lowest values of all the studied traits were obtained from plots untreated by soil mulching in both seasons (Table 4). This result may be due to the increase in salt accumulation on the soil surface after irrigation which is unavoidable due to high temperatures and high evaporation rate (Table 3) as is obvious within the study area, which caused a reduction in the plant height and yield attributes of pearl millet plants. Similar outcomes were obtained by Reiad et al. (2014).

Results in Table 4 emphasized the considerable effect of the irrigation water quantity on plant height and yield traits in both the 2019 and 2020 seasons. In this connection, 100% of the water requirement treatment recorded the highest values for all the above-mentioned traits, but statistically equaled 75% of the water requirement treatment, surpassing 50% of the water requirement treatment in both seasons. The potent treatment of 100% of the water requirement enhanced plant height by 33.8 and 33.5%, panicle length by 93.1 and 96.7%, the number of grains/panicle by 30.2 and 30.0%, grains weight/panicle by 70.3 and 66.2%, and seed index by 110.7 and 79.1% compared to 50% of the water requirement treatment in 2019 and 2020 seasons, respectively (Table 4). These results are consistent with those stated by Kalyani (2012), Kumar et al. (2015), Shubham et al. (2018).

The superiority of the high irrigation water quantity treatment (100% of the water requirement) over the previous traits may be due to the fact, that water is an essential component and acts as a carrier of nutrients for plant roots. The irrigation water increased soil moisture content and promoted sufficient moisture surrounding the roots zone, thereby reducing moisture stress, and helping pearl millet roots to absorb more water and nutrients from the soil which in turn accelerated the plant's growth rate (Mondal et al., 2012). As a result, irrigation water speeds up the photosynthesis process, eventually leading to the accumulation of more photosynthates, which have helped increase grain weight and the seed index (Kachhadiya et al., 2010; Ram et al., 2013). A continuous and favorable supply of moisture may also have permitted better vegetative growth leading to higher ear lengths (Kalyani, 2012; Kumar et al., 2015) and the number of grains/ear (Shubham et al., 2018). Contrariwise, the minimum values of the measured characteristics were obtained from plots that were irrigated with 50% of the water requirement in both seasons (Table 4). Similar findings were noted by Maqsood & Ali (2007), Seghatoleslami et al. (2008). This result may be attributed to the combined effect of water stress (50% of the water requirement) in addition to the prevailing heat stress in the study area which affected all the physiological processes such as photosynthesis and accumulation of lipids (Rizhsky et al., 2004). Subsequently, a decrease in the number of tillers and ears and plant height as compared to non-stress (well-watered) plants was obtained (Seghatoleslami et al., 2008).

Results in Table 4 revealed the positive effect of the combination between soil mulching rates and irrigation water quantity treatments on plant height, ear length, the number of grains/ear, grains weight/ear, and seed index in both seasons. Plots mulched by 9.5ton ha^{-1} of date palm residues with full irrigation provided the tallest plants and ear length values, which statistically equaled plots that received the same quantity of soil mulch and irrigated by 75% of the water requirement in both 2019 and 2020 seasons. While, the highest number of grains/ear, grain weight/ear, and seed index values were obtained by adding 7.2ton ha^{-1} of date palm residues as a soil mulch combined with 100% of the water requirement, which was statistically at par with plots received the same amount of soil mulch (7.2ton ha^{-1} of date palm residues) combined with 75% of the water requirement in both seasons (Table 4). The lowest values for plant height and yield attribute i.e. ear length, number of grains/ear, grains weight/ear, and seed index were recorded with the combination of no soil mulch application with 50% of the water requirement in both seasons.

Yields, grain protein content, and water use efficiency

Data in Table 5 show the massive impact of soil mulching rates on yields, i.e. biological and grain yields, grain protein content %, and WUE in both seasons. The addition of 7.2ton ha^{-1} date palm wastes as soil mulching attained the maximum values of biological and grain yields, and grain protein content in both seasons (Table 5). Using this rate of date palm waste as a soil mulching increased the biological yield by 109.3 and 108.1%, grain yield by 134.2 and 130.4%, and grain protein content % by 134.2 and 131.0% in 2019 and 2020 seasons, respectively compared to no soil mulching addition. Since soil mulching decreased the effect of solar radiation by serving as a physical barrier and improved the microclimate of the above-ground resulting in lower soil temperature than the bare soil (Ram et al., 2013), increased amount of soil organic matter (Yadav et al., 2019), which promoted nutrient absorption and a favorable growth condition available for the pearl millet crop during the main life cycle. Another positive effect of mulching is that it improves the soil water holding capacity for a longer period (Chakraborty et al., 2008), thereby soil mulching eventually significantly improved growth, and yield components (Table 4) and consequently crop yields (Table 5).

Concerning the WUE, each increase in soil mulching application from 2.4 up to 9.5tons per hectare led to a markedly increment in the WUE in both the 2019 and 2020 seasons (Table 5). Adding 9.5ton ha^{-1} date palm residues was the superior treatment and caused an increase in WUE by 133.9 and 130.3% in the first and second seasons, respectively as compared to no soil mulch treatments. Mulching provides a better environment for the soil in terms of preserving its moisture (Chakraborty et al., 2008), particularly during long dry periods (Table 3) when the crop has been subjected to water stress (75% of the water requirement). The maintenance of a cooler canopy and improved plant water status contributed to these favorable conditions within mulching (Lil et al., 2008). Overall, the high mulch application rate showed a good water-saving potential (25% of irrigation water quantity) with comparable growth and yield under heat stress conditions in pearl millet compared to no mulches, as shown in Table 5. Mulching practice not only affects soil surface but also improves soil water and thermal status, which play an important role in crop growth and development during dry farming. These findings are similarly trendy to those obtained by Abd El-Mageed et al. (2016), Singh et al. (2021).

TABLE 4. Pearl millet plant height and yield attributes as affected by mulching application rates, irrigation water quantities and their interactions in 2019 and 2020 seasons

Variable		Plant height (cm)		Panicle length (cm)		No. of grains/ panicle		Grains weight/ panicle (g)		Seed index (g)	
		2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Mulching rate (ton ha^{-1})											
0		156.3	160.0	18.4	18.8	771	786	15.6	16.3	6.3	6.9
2.4		173.5	175.4	20.6	21.4	823	836	19.4	20.1	8.6	9.1
4.8		187.4	191.6	22.2	23.9	881	897	20.5	21.2	9.9	10.1
7.2		202.1	207.1	25.1	26.8	965	977	22.3	22.9	10.7	11.4
9.5		217.9	228.8	27.3	28.2	942	953	21.6	21.8	10.1	10.5
LSD ($P_{0.05}$)		2.4	3.6	0.6	0.8	11	9	1.0	0.6	0.5	0.4
Irrigation water quantities											
100 % of the water requirement		215.1	219.3	28.2	30.1	982	995	24.7	25.1	11.8	12.0
75 % of the water requirement		212.5	217.6	26.6	27.8	971	984	23.5	23.9	10.8	11.2
50 % of the water requirement		160.7	164.2	14.6	15.3	754	765	14.5	15.1	5.6	6.7
LSD ($P_{0.05}$)		3.1	2.8	2.5	2.7	14	12	1.3	1.5	1.6	1.3
The interaction											
Without (0)	100 % of the water requirement	185.7	189.7	23.3	24.5	877	891	20.2	20.7	9.1	9.5
	75 % of the water requirement	184.8	188.8	22.3	23.4	871	885	19.6	20.1	8.6	9.1
	50 % of the water requirement	158.5	162.1	16.5	17.1	763	776	15.1	15.7	6.0	6.8
2.4 ton ha^{-1}	100 % of the water requirement	194.3	197.4	24.4	25.8	903	916	22.1	22.6	10.2	10.6
	75 % of the water requirement	193.5	196.5	23.6	24.7	897	911	21.5	22.1	9.7	10.2
	50 % of the water requirement	167.1	169.8	17.6	18.4	789	801	17.0	17.6	7.1	7.9
4.8 ton ha^{-1}	100 % of the water requirement	201.3	205.6	25.2	27.0	932	946	22.6	23.2	10.9	11.0
	75 % of the water requirement	200.2	204.6	24.4	25.9	926	940	22.0	22.7	10.5	10.4
	50 % of the water requirement	174.1	177.9	18.4	19.6	818	831	17.5	18.2	7.8	8.4
7.2 ton ha^{-1}	100 % of the water requirement	208.5	213.2	26.7	28.5	974	986	23.5	24.0	11.3	11.7
	75 % of the water requirement	207.4	212.1	25.8	27.3	968	981	22.8	23.5	10.8	11.1
	50 % of the water requirement	181.4	185.7	19.9	21.1	860	871	18.4	19.0	8.2	9.1
9.5 ton ha^{-1}	100 % of the water requirement	216.5	224.1	27.8	29.2	962	974	23.2	23.5	11.0	11.3
	75 % of the water requirement	215.4	223.0	27.6	28.0	956	969	22.5	23.0	10.6	10.9
	50 % of the water requirement	189.3	196.5	21.0	21.8	848	859	18.1	18.5	7.9	8.6
LSD ($P_{0.05}$)		1.2	1.3	1.1	1.3	7	6	0.8	0.6	0.5	0.7

TABLE 5. Pearl millet yields, grain protein content percentage, and water use efficiency as affected by mulching application rates, irrigation water quantities, and their interactions in 2019 and 2020 seasons

Variable		Yield/ha				Grain protein content (%)		WUE (kg/m³)	
		Biological (Ton)		Grain (Ton)					
		2019	2020	2019	2020	2019	2020	2019	2020
Mulching, palm residue quantities									
Without (0)		3.602	3.696	1.682	1.776	7.0	7.4	0.312	0.329
2.4 ton ha^{-1}		6.809	6.986	3.209	3.386	13.4	14.1	0.594	0.627
4.8 ton ha^{-1}		7.087	7.262	3.487	3.662	14.5	15.3	0.646	0.678
7.2 ton ha^{-1}		7.541	7.692	3.941	4.092	16.4	17.1	0.667	0.676
9.5 ton ha^{-1}		7.363	7.414	3.763	3.814	15.7	15.9	0.730	0.758
LSD ($P_{0.05}$)		0.130	0.118	0.053	0.074	0.7	0.5	0.030	0.023
Irrigation water quantities									
100 % of the water requirement		7.687	7.766	4.087	4.166	17.0	17.4	0.676	0.689
75 % of the water requirement		7.610	7.706	3.986	4.073	16.6	17.0	0.879	0.898
50 % of the water requirement		3.420	3.542	1.500	1.622	6.3	6.8	0.496	0.537
LSD ($P_{0.05}$)		0.089	0.067	0.132	0.103	0.2	0.3	0.145	0.123
The interaction									
Without (0)	100 % of the water requirement	5.645	5.731	2.885	2.971	12.0	12.4	0.494	0.509
	75 % of the water requirement	5.614	5.702	2.842	2.926	11.8	12.2	0.596	0.614
	50 % of the water requirement	3.511	3.619	1.591	1.699	6.6	7.1	0.404	0.433
2.4 ton ha^{-1}	100 % of the water requirement	7.248	7.378	3.648	3.778	15.2	15.7	0.635	0.658
	75 % of the water requirement	7.210	7.346	3.367	3.730	15.0	15.5	0.737	0.763
	50 % of the water requirement	5.114	5.266	2.354	2.506	9.8	10.4	0.545	0.582
4.8 ton ha^{-1}	100 % of the water requirement	7.387	7.514	3.787	3.914	15.8	16.3	0.661	0.684
	75 % of the water requirement	7.356	7.486	3.746	3.869	15.6	16.1	0.763	0.788
	50 % of the water requirement	5.254	5.402	2.494	2.642	10.4	11.0	0.571	0.608
7.2 ton ha^{-1}	100 % of the water requirement	7.615	7.730	4.015	4.130	16.7	17.2	0.672	0.683
	75 % of the water requirement	7.584	7.699	3.979	4.082	16.5	17.0	0.773	0.787
	50 % of the water requirement	5.482	5.618	2.722	2.858	11.3	11.9	0.582	0.607
9.5 ton ha^{-1}	100 % of the water requirement	7.526	7.591	3.926	3.991	16.4	16.6	0.703	0.724
	75 % of the water requirement	7.493	7.560	3.881	3.948	16.1	16.4	0.805	0.828
	50 % of the water requirement	5.393	5.479	2.633	2.719	11.0	11.3	0.613	0.648
LSD ($P_{0.05}$)		0.036	0.041	0.048	0.053	0.1	0.2	0.028	0.019

The lowest values for these characteristics were obtained in plots, which were not treated with soil mulching in both seasons (Table 5). These results might be due to the negative impact of heat stress during the growing seasons, which reduces essential nutrient uptake and accumulation, in addition to increases the water evaporation from the soil surface (Prasad et al., 2008).

Regarding the effect of irrigation water amounts on biological and grain yields, grain protein content %, and WUE, the findings in Table 5 showed that all the above-mentioned characters were significantly affected by the irrigation water levels in both seasons. Plots that received 100% of the water requirement treatment gave the highest values of biological and grain yields of pearl millet, and grain protein content %, with no significant difference with the plots that received 75% of the water requirement treatment in both seasons (Table 5). Application of 100% of the water requirement promoted each of biological yield by 124.7 and 119.2%, grain yield by 172.4 and 156.8%, and grain protein content % by 169.8 and 155.8% in 2019 and 2020 seasons, respectively compared to lower levels (50% of the water requirement treatment). The massive impact of the full irrigation treatment on pearl millet yields and protein content % may be due to the availability of sufficient soil moisture in the root zone during the life cycle of the pearl millet plant, where more water was provided, cell division, cell elongation, cell turgidity, the better opening of stomata, increased absorption and nutrient transport, and eventually increased photosynthesis partitioning to sink, resulting in better growth potential (Tomar, 2001), which significantly stimulated yield characteristics and grain yield (Kumar et al., 2015).

The medium irrigation level treatment (75% of the water requirement) gave the highest WUE value and increased by 77.2 and 67.2% in the first and second seasons, respectively compared with the plots irrigated by the minimum amount of irrigation water treatment (50% of the water requirement) as shown in Table 5. Therefore, irrigating pearl millet plants at 75% is recommended under insufficient water supply to achieve not only the same yields but also to conserve more water compared to full irrigation treatment. These findings are close to those of Patel et al. (2013).

Plots watered by 50% of the water requirement treatment recorded the lowest values of pearl millet yields, grain protein content %, and WUE in both seasons (Table 5). These results clarified that limited water supply often results in reduced crop yield and low water productivity, which is due to the negative impact of increased grain respiratory losses on photosynthesis under the low water supply in combination with very extreme temperatures above 40°C (Prasad et al., 2008), and this may be responsible for the increased yield loss under heat stress conditions (Wardlaw et al., 1980). Also, the effects of drought and heat stress on whole-plant processes including but are not limited to germination, leaf growth, root, tiller and stem, dry matter development, pollination, fertilization, and grain yield (Prasad et al., 2008). Maqsood & Ali (2007) and Seghatoleslami et al. (2008) also showed that the grain yield of pearl millet was reduced by water stress.

The interaction of fully irrigated pearl millet plants combined with 7.2ton ha^{-1} date palm as soil mulch gave the highest values of pearl millet yields and grain protein content statistically leveling the interaction of 75% of the water requirement with 7.2ton ha^{-1} date palm in both seasons (Table 5). These results are in a similar trend with those of Ram et al. (2013), and Chakraborty et al. (2008), who found that rice husk mulching would be advantageous for wheat under minimal irrigation conditions as it can maintain better soil and plant water status, leading to higher grain yield. In another study, a consistently lower salt content was recorded in the 0-20cm soil layer for mulched irrigation treatment than for non-mulched irrigation treatment (Abd El-Mageed et al., 2016). In part, this may be due to the fact, that mulch can effectively hold water that has avoided run-off and infiltrated the soil profile, and therefore the salts accumulated in the topsoil can be washed to deeper soil layers (Li et al., 2013), leading to the highest pearl millet yields (Table 5).

Moreover, the interaction between 9.5ton ha^{-1} soil mulch applied and the medium irrigation level (75% of water requirement) attained the maximum value of WUE in the 2019 and 2020 seasons. These results are in a parallel line with those of Chakraborty et al. (2008), and Ram et al. (2013), who observed that under limited irrigation conditions, rice husk mulching was beneficial for wheat as it can maintain better soil and plant water status, leading to higher water use efficiency.

Conclusion

Given the above results, the findings of the current study indicate that the soil mulch had a positive impact on the storage of soil water, soil temperature, and crop yield. Appropriate soil mulch rates are therefore very important for sustainable agricultural development in such desert areas. The combination of 7.2 ton ha^{-1} date palm residues as a soil mulching and 75% of the water requirement had a synergistic effect and had a promising effect on pearl millet yields, yield components, protein content % and WUE. Mulch with palm date wastes, therefore, appears to be a solution for reducing air pollution on one hand and reducing soil evaporation, increasing nutrients availability, soil organic, and protecting the soil from wind and water erosion on the other hand. Also, from the environmental point of view, mulching using crop wastes ensures an environmentally friendly practice of wastes disposal. It is also very important to take water-saving measures to reduce the requirements for irrigation water in this area. Therefore, to secure higher summer pearl millet yields and WUE under heat stress and scarce water, it could be recommended that the crop be irrigated by 75% of its requirement alongside mulching of date palm residues at a rate of 7.2 tons ha^{-1}. Besides, plots irrigated by 75% of the water requirement are statistically equal to plots irrigated by 100% of the water requirement for pearl millet yields, resulting in 25% irrigation water savings and yields being similar to the higher irrigation level.

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تأثير كميات ماء الرى وتغطية سطح التربة على أداء الدخن تحت ظروف الإجهاد الحرارى

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يعتبر الجفاف والإجهاد الحراري من أكثر الإجهادات اللاأحيائية التي تؤثر على إنتاج المحاصيل في المناطق الصحراوية. وبناء على ذلك أجريت تجربتان حقليتين خلال عامى 2019 و2020 بمحطة بحوث التجارب الزراعية في واحة الخارجة بمحافظة الوادي الجديد التابعة لمركز بحوث الصحراء، لدراسة استجابة الدخن لثلاث مستويات من مياه الري (100 و 75 و 50% من الإحتياج المائى) وخمس معدلات من تغطية سطح التربة (0، 2.4، 4.8، 7.2، 9.5 طن/هكتار) فى ظل ظروف ندرة المياه والإجهاد الحراري السائدان بالمنطقة. أظهرت النتائج المتحصل أن محصول الدخن وصفات المحصول بالإضافة إلى محتوى بروتين الحبوب وكفاءة استخدام المياه تأثرت معنويا بتغطية سطح التربة وكميات ماء الرى وتفاعلاتهما في كلا الموسمين. أعطت معاملة تغطية سطح التربة بإضافة 9.5 طن/هكتار أعلى القيم لصفات ارتفاع النبات وطول القنديل وكفاءة استخدام الماء مقارنة مع معاملة بدون تغطية سطح التربة في كلا الموسمين، بينما سجلت معاملة تغطية سطح التربة بإضافة 7.2 طن/هكتار أعلى القيم لصفات عدد الحبوب/القنديل ووزن الحبوب/القنديل ودليل البذور بالإضافة إلى المحصول البيولوجى ومحصول الحبوب ومحتوى بروتين الحبوب مقارنة مع معاملة بدون تغطية سطح التربة في كلا الموسمين. سجلت معاملة الرى الكامل (100% من الإحتياج المائى) أعلى القيم لكل الصفات المدروسة باستثناء صفة كفاءة استخدام الماء، وهى تتساوى احصائيا مع معاملة 75% من الإحتياج المائى، وكلاهما أعلى معنويا من معاملة 50% من الإحتياج المائى في كلا الموسمين. يمكن أن نستنتج من الدراسة الحالية أن إضافة 7.2 طن/هكتار لتغطية سطح التربة مع 75% من الإحتياج المائى ربما تكون الممارسة المثلى لتحسين إنتاجية الدخن بالمناطق شديدة الجفاف.