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Meteorological factors and their influence on grain sorghum yield and evapotranspiration under unirrigated and irrigated conditions

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Abstract

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The aim of the experiment was to determine the effect of meteorological factors during the growing season of grain sorghum on yield and evapotranspiration. The experiment was conducted in the period 2018 – 2019 on meadow-cinnamon soil in the experimental field of Agricultural Institute – Stara Zagora. Data from irrigated (at 75% FC) and non-irrigated grain sorghum were used. The relationships between grain yield and meteorological factors as well as topsoil dewatering were established. The evapotranspiration value was calculated (168.3–183.7 mm without irrigation and 264.3–283.8 mm under optimum irrigation). The yields obtained from grain sorghum were highly dependent on the climatic conditions of the different years of the study, ranging from 6140 kg.ha to 7424 kg.ha under irrigated and non-irrigated conditions, respectively.

Keywords: meteorological factor; sorghum; yield; evapotranspiration

Introduction

With the help of appropriate agronomic techniques for sorghum cultivation and selection, stable yields can be obtained under extreme climatic conditions (Enchev & Kikindonov, 2015; Zarkov & Atanasova, 2008). Therefore, in recent years it has become an increasingly widely studied crop in Bulgaria under non-irrigated conditions. However, there is still very little research on sorghum grown under irrigated conditions in our country (Gramatikov et al., 2002). For the Burgas region Tanchev & Ivanov (1995) found that sorghum irrigated once exceeded maize irrigated twice or thrice (by 26% and 12%, respectively) in grain yield over an average of three years, and approached that obtained from maize irrigated four times. Sorghum responds well to irrigation, even though it is a drought-tolerant crop, and when grown under unstable natural moisture conditions, a good knowledge of its evapotranspiration is necessary for accurate determination and operational prediction of irrigation (Bazitov, 2023). The determination of evapotranspiration of field crops is essential for the development of a design irrigation regime (Bazitov, 2020; 2021; Matev & Petrova, 2012; López-Urrea et al., 2016). There are not many publications on grain sorghum cultivation under irrigated conditions in our country. For India in the Central Soil Salinity Research Institute, Karnal, found that in grain sorghum, the average daily ET was 3 mm/d at the initial stage, then peaked at 6 mm/d between 8 and 9 weeks after sowing and declined to 4 mm/d during the maturity stage, with the cumulative ET of sorghum reaching 495 mm (Tyagi et al., 2000). Seasonal evapotranspiration for grain sorghum for the Garden City, Manhattan, and Tribune regions of Kansas ranged from 457 to 570, 444 to 514, and 530 to 765 mm, resp. (Rogers et al., 2015). In western Kansas, resulting grain sorghum yields increased linearly with increasing irrigation rate (Klocke et al., 2012). A maximum seasonal evapotranspiration for the Zaragoza region (Spain) of 588 mm has been reported for grain sorghum (Farré & Faci, 2006). The water use for sorghum, with a growing season duration of 110-130 days, varied between 450 and 750 mm, depending on the evapotranspiration level (Wani et al., 2012). Irrigation rates for biomass production from sorghum grown in Foggia, Italy were found to vary between 633 and 768 mm (Garofalo & Rinaldi, 2013). With the present study, we aimed to determine the influence of meteorological factors and their impact on the yield and evapotranspiration of grain sorghum grown on meadow cinnamon soil for the region of southern Bulgaria under irrigation and without irrigation.

Materials and Methods

In the period 2018–2019, in the experimental field of Agricultural Institute – Stara Zagora, on soil type meadow-cinnamon, soil was conducted with sorghum, medium-crop variety Maxired. The soil type is characterized by the following water-physical properties: field capacity (FC)- 26.57%, fade coefficient – 18.19%, porosity – 47% and bulk density – 1.45 kg/ m^3. The trial was laid out using the block method in four replications, with a harvest plot size of 25 m^2. Sorghum was harvested at the full grain maturity stage. Irrigation was carried out by gravity with seasonal flexible polyethylene piping. The following variants were studied: variant 1 – no irrigation (control); variant 2 – optimal irrigation, 75–80% of the FC (100% irrigation rate). Evapotranspiration (ET) for the growing season was established by water balance calculations under optimal irrigation Option 2 for the 0–80 cm layer using the formula: ET = Wnach – Wkr + N + m, where: ET – evapotranspiration in mm, Wnach – water balance at the beginning of the study period in mm, Wkr – water balance at the end of the study period in mm, N – amount of precipitation that fell in the study period in mm, m – irrigation rate in mm.

During the growing period of sorghum, three irrigations were implemented in variant 2 in order to maintain 75-80% pre-field moisture content (PFC). The mathematical processing of the data was done by MS Excel software (ANOVA- 1 module).

Results and Discussion

The amount of rainfall that fell during their growing season in different years is insignificant. The year 2018 is characterized by the most precipitation -310.3 mm, followed by 2019 with a total of 253.5 mm. On average over the study years, the rainfall amount is 7 mm. higher than that of the multiyear period. Both for the two study years, and for the multiyear period, June is characterized as the most important month. The rainfall for the months and years of study averaged over the multiyear period exceeded that for the long-term period by 9.9 mm (Table 1). During the years of the study, three irrigations were submitted from with the aim of maintaining 75–80% of the FC (field capacity) (Table 2). Temperature is the other main meteorological factor that influences the uniform germination of seeds, the timely onset of the different crop phases and the formation of the yield size (Table 3). When the mean daily temperatures measured in the year of study were compared with the multi-year period for the same months, there was no clear trend for higher or lower values. The temperature measurements in both cases are similar, with the sum of the indicated months being close to those of the multi-year period.

Table 2. Number of irrigations and irrigation rate by years

Years	Number of irrigations	Irrigation depth, mm
2018	3	60
2019	3	70

The yields obtained from sorghum are the result of the joint action of meteorological and agronomic factors established during the experimental years. The effect of the factors air temperature and rainfall is much more pronounced in the non-irrigated crop (Table 4). During the period of active vegetation, in spite of the uneven rainfall and during the experimental years, we obtained relatively stable yields from 6140 kg/ha to 7509 kg/ha, which is due to the good drought resistance of the sorghum variety studied, Maxired. By optimizing the moisture factor, high and stable yields were obtained, which did not differ significantly between the years of the study. In irrigated sorghum, the yield increase was on average 19.3% higher than in non-irrigated sorghum. The yields obtained by year between the different variants and on average over the period studied were very well proven.

Table 1. Sum of rainfall during the sorghum growing season

Years	Months					
	May	June	July	August	September	Sum, mm
2018	99.3	85.3	75.2	25.2	25.3	310.3
2019	63.5	108.7	52.0	11.1	18.2	253.5
Average for the period 2018–2019	81.4	97.05	63.6	18.2	21.75	282.0
Average for the multi-year period 1930–2019	70.25	92.8	43.15	17.95	23.3	247.4

Table 3. Average day-night temperatures by month during the sorghum growing season

Years	Months					
	May	June	July	August	September	Sum,mm
2018	19.4	21.8	23.7	25.1	22.8	112.8
2019	17.4	23.4	23.8	25.2	20.6	110.4
Average for the period 2018–2019	18.03	21.9	24.3	25.2	21.7	111.06
Average for the multi-year period 1930–2019	18.35	22.5	23.9	25.0	21.3	111.1

Table 4. Yields by variant and years

	Yield, kg/ha	Compared to Variant 1		Compared to Variant 2	
		+/−Yeld	%	+/−Yeld	%
2018					
1. Non-irrigated	6140	St.	100.0	– 1599	83,6
2. Optimal irrigated	7339	+ 1599	119.5	St.	100.0
GD 5% 54/61 = kg/ha; 1% = 80.80 kg/ha; 0.1% 120.48 = kg/ha					
2019					
1. Non-irrigated	6300	St.	100.0	– 1209	83,8
2. Optimal irrigated	7509	+ 1209	119.1	St.	100.0
GD 5% 68.92 = kg/ha; 1% = 103.16 kg/ha; 0.1% = 143.98 kg/ha					
2018–2019					
1. Non-irrigated	6220	St.	100.0	– 1204	87.3
2. Optimal irrigated	7424	+ 1204	119.3	St.	100.0
GD 5% = 61.76 kg/ha; 1% = 91.98 kg/ha; 0.1% = 132.23 kg/ha					

In sorghum, evapotranspiration (ET) was determined by both the specific meteorological conditions of the experimental years and the irrigation regime applied values of the cumulative ET from the 0–80 cm layer under non-irrigated and irrigated catchments are presented by year and on average over the period in Table 5. On average over the two years of the study, irrigation increased sorghum water use by 26.8–27.4% with the largest increase in ET in 2018 when there is also the greatest stress on the meteorological factors: temperature and humidity deficit. However, in absolute terms, the values of the cumulative ET is in line with the specific meteorological conditions. In open field cultivation, the water consumption of sorghum is mainly shaped by the growing season rainfall, the initial water reserve (accumulated in the non-growing season) and the irrigation rate (if the crop is grown under irrigated conditions).

For proper prediction of irrigation timing, it is necessary to study the average daily ET run. Figures 1 and 2 present the data by year, under non-irrigated and irrigated conditions, respectively. Under non-irrigated conditions in the experimental years, irrespective of meteorological differences, the ET run depends on the water availability of the soil and the rainfall used during the sorghum growing season. Evapotranspiration in the initial stages of crop development was low, but water availability was sufficient for its normal course. Regardless of the amount of precipitation in the variants with natural wetting, daily average ET values did not exceed 4.2 mm (end of July – beginning of August – 2018). Until the beginning of the irrigation period, ET in both variants is almost the same, after which its values increase in the irrigated variant due to the favourable conditions created by irrigation. The maxi-

Table 5. Total evapotranspiration by years and average 2018–2019

Years	Variants	ET mm	Compared to non irrigated		Compared to irrigated	
			± (mm)	%	± (mm)	%
2018	Non irrigated	282.2	0.0	100	-77.3	78.4
	Irrigated	359.5	77.3	127.4	0.0	100
2019	Non irrigated	272.4	0.0	100	-73,.0	78.8
	Irrigated	345.4	73.0	126,8	0.0	100
Averaga	Non irrigated	277.3	0.0	100	-59,1	78.6
	Irrigated	352.5	59,1	127.1	0.0	100

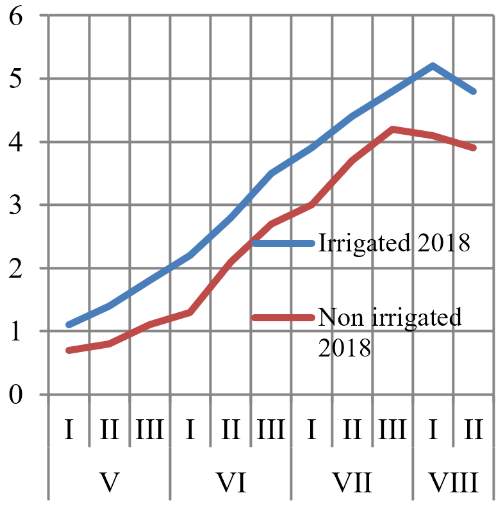

Fig. 1. Daily evapotanspiration, mm during 2018

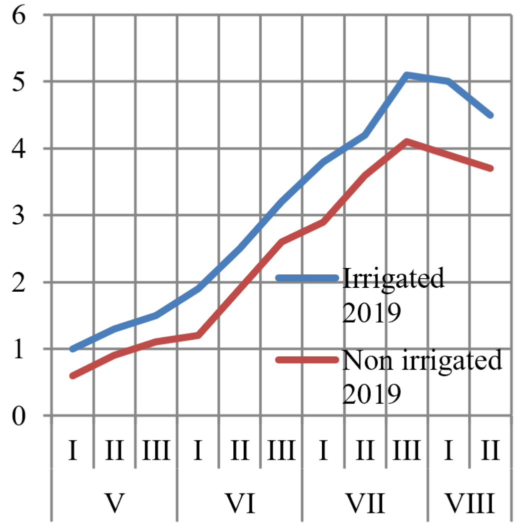

Fig. 2. Daily evapotanspiration, mm during 2019

mum in the irrigated variant was recorded in the first ten days of August 2018 – 5.2 mm, after which it gradually began to decrease and towards the end of the growing season reached values similar to those at the beginning of the vegetation period. When grown in open areas, the ET of sorghum is mainly formed by the growing season rainfall, the initial water reserve (accumulated after harvesting the precursor) and the irrigation rate (if the crop is grown under irrigated conditions). The average data for the years of the study concerning the formation of sorghum water use in the 0–80 cm layer are presented in Figures 3 and 4 and by year in Table 6.

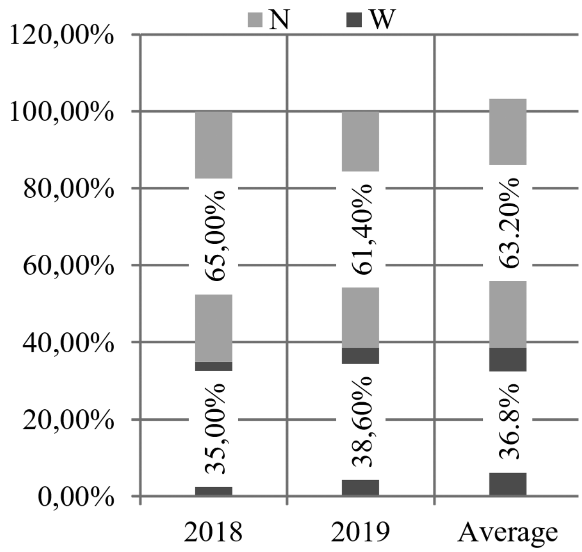

Fig. 3. Relative formation of ET in layer 0–80 cm non irrigated

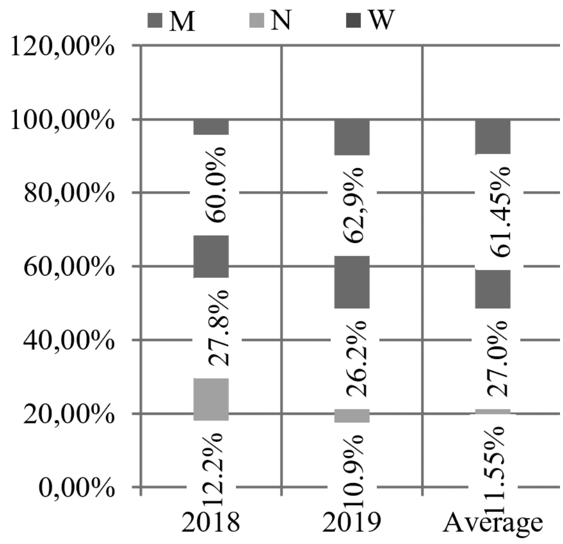

Fig. 4. Relative formation of ET in layer 0–80 cm optimum irrigation

In the variant non irrigation of sorghum, the main part of its ET is formed by the remaining water quantity in the active soil layer, or the so-called initial water reserve and the amount of usable precipitation during the vegetation period, which provides an average of 63.20% of the ET for the 0-80 cm layer, with the remaining 36.80% being accounted for by moisture reserves (headwater balance) (Figure 3). In the variant with sorghum irrigation, the irrigation rate increases

Table 6. ET formation in sorghum by year under irrigated and non-irrigated conditions

Indicator	Non irrigated		Irrigated		Non irrigated		Irrigated	
	mm	%	mm	%	mm	%	mm	%
	2018				2019			
ΣET	282.2	100	359.5	100	272.4	100	345.4	100
W	97.77	35.0	43.8	12.2	105.1	38.6	37.6	10.9
N	183.40	65.0	99.9	27.8	167.3	61,4	90.5	26.2
M	–	–	215.7	60.0	–	–	217.2	62.9

2018– 2019				
Indicator	Non irrigated		Irrigated	
	mm	%	mm	%
ΣET	277.2	100	352.5	100
W	101.43	36.8	40.7	11.55
N	175.35	63.2	95.2	27.0
M	–	–	217.2	61.45

ΣET – total evapotranspiration
W – initial water supply
N – precipitation during vegetation period
M – irrigation depht

the values of total ET, a part of it participates in its formation, at the expense of usable precipitation and available soil moisture stock and occupies on average 61.45% of water discharge (Figure 4).

Conclusion

The grain sorghum is highly productive under non-irrigated conditions, yet its yields are influenced by the climatic conditions of the different study years, ranging from 6140 kg/ha to 6300 кg/ha.

Irrigation significantly reduces the influence of weather factors and contributes to more stable yields (7339 kg.ha to 7509 kg.ha).

The sum of evapotranspiration in the non-irrigated grain sorghum ranged from 272.2 to 282.2 mm. Maximum daily averages reach 4.6 mm in the third ten days of July, depending on weather conditions.

In irrigated grain sorghum, the total evapotranspiration ranged from 345.4 to 359.5 mm. Its maximum daily mean values, reaching up to 5.2 mm, were obtained in the first ten days of August.

On average over the years of the experiment, precipitation formed more than half of the ET in non-irrigated sudangrass and a minor fraction in irrigated grain sorghum. The irrigation rate of over 61.45% was significant, which confirmed the importance of irrigation in the cultivation of the crop for the region of Stara Zagora.

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