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Evapotranspiration of sunflower crops depending on irrigation

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Abstract. *The aim of the study is to analyze the influence of irrigation regime on evapotranspiration (ET) of sunflower, in terms of total and average daily values, its effectiveness in terms of yield, and the peculiarities of its formation. The field experiment was conducted in the region of Plovdiv, with hybrid PR-64-E-83. The variants of the study are: without irrigation, optimal irrigation with initial humidity at 75% of FC for the layer 0–80 cm and irrigation with 50% and 150 % of irrigation rate, respectively. Seasonal evapotranspiration of sunflower varies from 274 to 342 mm. Irrigation with 50% of the optimal irrigation depth causes ET increasing with an average of 33.1% (from 26.1 to 37.4%). The optimally irrigated sunflower uses from 475 to 559 mm. Increase of ET as compared with the rainfed sunflower is an average of 67%. In case of irrigation with 150% of the irrigation depth ET increases with extra 2.5 – 26.7% (an average of 13.5%). ET of sunflower was formed in the following way for the conditions of the experiment: In rain-fed conditions rainfalls share 49 – 82% and water supply – from 18 to 51% of ET. By irrigation with 50% of rate the sharing of rainfalls is 36-64%, for water supply is 17-33% and irrigation depth – 14-31%. By optimum irrigation sharing is respectively 28-56%, 16-23% and 25-49%. The maximum value of daily ET for rainfed sunflower varying from 3.3 to 5.6 mm. Irrigation with norm of 50% increases values of ET to 5.2 – 6.1 mm. The maximal value of this regime of irrigation is most often in the flowering period. In case of optimal irrigation the maximal values of daily ET will remain the same usually to the beginning of phase „seeds fill", and the values are between 6 and 7 mm.*

Keywords: sunflower, evaportanspirarion, water deficit, irrigation

Introduction

Sunflower is a crop consuming significant amounts of water to form a unit yield. Obtaining maximum yields for the specific growing conditions and the specific hybrid is related to the provision of the water to be consumed by plants from sowing until the seeds mature. During the vegetation period a plant consumes between 500 and 600 mm of water, with rainfall (for the period April-September) rarely exceeding 250-350 mm, i.e. irrigation must ensure the rest of the evapotranspiration (ET). According to Göksoy et al. (2004) and Demir et al. (2006) different irrigation regimes have significant effect on aggregate evapotranspiration of sunflower, and with an optimal irrigation it can reach and exceed 670 mm. When growing in the lysimeter at high air temperature, the crop ET can reach 765-882 mm, and at the time of flowering it is possible to reach average daily values of 13 mm (Karam et al., 2007). For the region of Lavras (Brazil) ET of the optimally irrigated sunflower is 428.7 mm. Reducing irrigation rates by 25% reduces its value down to 350.8 mm. Non-irrigated sunflower consumes only 117.2 mm, and with an increase in the rate of 30% evapotranspiration increased by about 22%, although the yield was not significantly altered (Silva et al., 2007).

Evapotranspiration of sunflower during the period from germination to bud formation is not too intense, representing 20-25% of total value, however, the formation of 3-6 pairs of leaves (when inflorescence is formed) is a critical period in terms of soil moisture. For the local conditions, however, according to Delibaltov et al. (1973) natural humidity is enough for the normal growth in that period. The most intensive evapotranspiration of sunflower plants is during the intensive linear growth (from bud formation to full flowering) and during the flowering when for a period of 20-30 days they may form up to 55-60% of total evapotranspiration, and during the third period - about 25%. According to Mihov (1974), average daily evapotranspiration of sunflower has the character of the curve with the following pattern: from germination to the first ten days of May (including) it gradually increases from 1,0 to 2,1 mm. After this period the increase is much more intense and depending on the level of the soil moisture its values reach their respective maximum at different times. Under rainfed conditions, the maximum daily average ET is 5.3 – 5.5 mm and is in the third decade of June. Under irrigated conditions the maximum is within 7.5 – 7.7 mm and occurs in the second decade of July. This coincides with the period of mass flowering and the start of grain ripening. After this period its values begin gradually to decrease due to the lower impact of meteorological factors and gradual fading of physiological processes.

The analysis of Ivanov (1972) for conditions of low leached chernozem in Dobrudja showed that 46.5 to 48.0% of non-irrigated sunflower ET is formed by precipitation, and the rest – from the autumn-winter humidity. According to this author, the coefficient of the sunflower evapotranspiration to obtain 1 kg seeds with optimal moisture is 1.38 – 1.56 mm, and for 1 kg of oil – 2.92 – 3.23 mm. By improving the selection and introduction of new high-yield hybrids, ET productivity increases significantly, and according to Demir, et al. (2006) 1 mm evapotranspiration corresponds to 7.8 kg/ha yields.

In recent years, sunflower has again become a favorite field crop for growing. This is a prerequisite for experiments related to the optimization of irrigation of the crop and for obtaining the highest possible yields in the presence of limited water resources. An integral part of this type of studies is evapotranspiration as a major consumption element in the soil water balance. The aim of the study is to analyze the influence of irrigation regime on evapotranspiration of sunflower, in terms of total and average daily values, its effectiveness in terms of yield, and the peculiarities of its formation.

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Material and methods

The analysis of the influence of irrigation regime on evapotranspiration of sunflower was based on data from field experiment conducted in the period 2004 – 2010 (excluding 2005) in the region of experimental training field of Department of Surveying and Land Reclamation, Agrarian University, Plovdiv, on alluvial meadow soils (formerly waterlogged). According to Meranzova (1990) characteristics of the soil in the experimental field are: density α = 1.39 t/m3; δ^{FC}= 29.4 (humidity at field capacity (FC), %); W^{max} = 326.9 mm; W^{min} = 245.2 mm (with 75% of FC).

The experiment was carried out with hybrid PR-64-E-83, crop density of 5500 plants per acre and row spacing of 70cm. The variants relating to this study are: 1) without irrigation, 2) irrigation with 50% of irrigation rate calculated for the optimal variant, 3) optimal irrigation with initial humidity at 75% of FC for the layer 0-80 cm; 4) irrigation 150% of irrigation rate. In 2004, the options are as follows: no irrigation and irrigation rate 25, 50, 75 and 100%. The number of irrigations and time for their implementation in all versions of the same experiment are the same and is fully in accordance with the requirements for optimal version, and an adjustment is made in the amount of irrigation norms. Irrigation is done by gravity on short closed furrows. The experiment is carried out with the block method in four replications with experimental plot area 30 m^2, and the harvest plot area – 10 m^2. The dynamics of soil moisture was monitored in all variants in 7 – 10 days layer by layer every 10 cm, depth of 1m, by the weighting method. The total ET was also calculated for all variants of the experiment through monitoring the balance of water supply and loss in soil layer 0 – 80 cm. The balance incorporates water supply elements such as usable rainfall, determined by the method of successive approximations (Krafti, 1964), and irrigation rates, if there was any irrigation during the relevant period. The average rate of ET is determined by ten days, calculated ET values are mapped in a rectangular coordinate system for each period including the time between two soil samples. Between them, the curve of ET is drawn so that after drawing a line between it and the X-axis to obtain the amount equal to the total ET.

Productivity of evapotranspiration has been established in two ways: 1) ET (mm) to obtain a yield of 1kg/ha; 2) yield (kg/ha) for 1 mm ET. During the years of the experiment all major agricultural events were observed related to technology adopted for the country for growing the specific crop.

Results and discussion

Evapotranspiration of each crop, including sunflower is significantly influenced by the meteorological conditions of the year (rainfall, temperature and humidity deficit of the air). In terms of precipitation 2004, 2006, 2008 and 2010 are considered average years. 2007 is considered as very moist, but at the same time it is extremely dry in the critical periods of vegetation of sunflower. With probability of 69.4%, 2009 can be defined as medium dry. With respect to the average temperature, the first experimental year (2004) is a medium to medium cool, but 2007, 2009 and 2010 are very warm. Quite similar in meteorological terms are 2006 and 2008, the same indicator characterizing them as moderately warm.

Although it is very dynamic as values, the air humidity deficit is crucial for the intensity of ET, especially with a sufficient amount of available soil moisture. In respect of this indicator 2007 is very dry, 2004 is dry and 2010 is medium. The remaining three years of the experiment are moderately dry. Data for providing the meteorological factors that determine the ET are presented in Table 1. The table also contains the total absolute values of each factor for the period V – IX, and data on multi-year average values.

Table1. Probability of precipitations, temperature and water pressure deficit in Plovdiv region for V - IX period

Factor		All experimental years						
		Average for multi year period	2004	2006	2007	2008	2009	2010
ΣT°	°C	3181 °C (for 93 years)	3135	3239	3367	3243	3326	3331
	P %		60.64	36.17	9.57	35.11	13.83	12.77
ΣD	HPa	1430 HPa (for 74 years)	1675	1590	1794	1587	1629	1441
	P %		13.33	21.33	6.67	22.67	18.67	50.67
N	mm	241.9 mm (for 97 years)	233.5	228.0	463.2	231.0	190.2	234.3
	P %		44.90	50.00	2.04	45.92	69.39	43.88

ΣT° – sum of temperature; ΣD – sum of water pressure deficit; N – precipitations;
P% – empirical probability of meteorological factors

Seasonal (total) evapotranspiration

Apart from weather conditions, ET depends on species and variety characteristics of the crops, length of vegetation period, as well as on the water regime in the active soil layer. Data on the influence of irrigation regime on seasonal (total) evapotranspiration of the tested sunflower hybrid are shown in Table 2. Despite the differences in meteorological terms, ET of non-irrigated sunflower in the different years of experiment varies in relatively narrow range with the lowest values – in the averagely dry and hot 2009 (274.4 mm). In the years with medium rainfall values (2004, 2006, 2008 and 2010) ET ranged 302 – 331 mm. The ability of sunflower to deal with short-term drought without significantly affecting its life processes also contributes for this minor variation. Although for the period 10 June to 31 July rainfall is only 4.2 mm, 2007 is the wettest year of the experiment. Rainfall during the third decade of May (124 mm) and the first ten days of June (129.3 mm) ensures sufficient moisture readily accessible till the start of the period of seed-fill. Under such conditions, combined with high air temperatures and low relative humidity ET during the period of bud formation-flowering-growth of flower head is maximal and that coincides with the biological maximum of ET in sunflower. Therefore, the total evapotranspiration of rainfed sunflower in 2007 was

Table 2. Seasonal evapotranspiration of sunflower by variants and years. Evapotranspiration formation

Variants	ET (mm)	ET (relative)		Precipitations		Irrigation depth		Soil water	
		to 0%	to 100%	mm	%	mm	%	mm	%
				2004					
no irrigated	330.8	100.0	66.2	215.4	65.1	0.0	0.0	115.4	34.9
25% m	385.4	116.5	77.1	215.4	55.9	54.3	14.1	115.7	30.0
50% m	417.2	126.1	83.5	215.4	51.6	108.6	26.0	93.2	22.4
75% m	431.5	130.4	86.3	215.4	49.9	162.9	37.7	53.2	12.4
100% m	499.9	151.1	100.0	215.4	43.1	216.9	43.4	67.6	13.5
				2006					
no irrigated	302.4	100.0	60.7	172.3	57.0	0.0	0.0	130.1	43.0
50% m	394.6	130.5	79.2	172.3	43.7	120.0	30.4	102.3	25.9
100% m	498.0	164.7	100.0	172.3	34.6	240.0	48.2	85.7	17.2
150% m	630.9	208.6	126.7	172.3	27.3	348.7	55.3	109.9	17.4
				2007					
no irrigated	341.7	100.0	68.5	280.7	82.1	0.0	0.0	61.0	17.9
50% m	437.5	128.0	87.8	280.7	64.2	62.3	14.2	94.5	21.6
100% m	498.5	145.9	100.0	280.7	56.3	124.6	25.0	93.2	18.7
150% m	571.6	167.3	114.7	280.7	49.1	186.9	32.7	104.0	18.2
				2008					
no irrigated	313.4	100.0	57.2	154.4	49.3	0.0	0.0	159.0	50.7
50% m	430.5	137.4	78.6	154.4	35.9	134.9	31.3	141.2	32.8
100% m	547.6	174.7	100.0	154.4	28.2	268.7	49.1	124.5	22.7
150% m	592.8	189.2	108.3	153.0	25.8	333.2	56.2	106.6	18.0
				2009					
no irrigated	274.4	100.0	57.8	174.3	63.5	0.0	0.0	100.1	36.5
50% m	374.5	136.5	78.9	174.3	46.5	115.7	30.9	84.5	22.6
100% m	474.7	173.0	100.0	162.2	34.2	231.3	48.7	81.2	17.1
150% m	486.8	177.4	102.5	148.5	30.5	257.1	52.8	81.2	16.7
				2010					
no irrigated	311.0	100.0	55.7	221.6	71.3	0.0	0.0	89.4	28.7
50% m	416.4	133.9	74.5	221.6	53.2	123.6	29.7	71.2	17.1
100% m	558.6	179.6	100.0	221.6	39.7	246.9	44.2	90.1	16.1
150% m	643.3	206.8	115.2	207.8	32.3	342.1	53.2	93.4	14.5
				Average for 2006 – 2010					
no irrigated	308.6	100.0	59.9	200.7	65.0	0.0	0.0	107.9	35.0
50% m	410.7	133.1	79.7	200.7	48.9	111.3	27.1	98.7	24.0
100% m	515.5	167.0	100.0	198.2	38.4	222.3	43.1	95.0	18.5
150% m	585.1	189.6	113.5	192.5	32.9	293.6	50.2	99.0	16.9

*m – irrigation rate

comparatively higher than in other years and it is 341.7 mm. As an average for the whole period of experiment values for this option are 308.6 mm.

Partially or fully restoring the readily available moisture in the active soil layer, irrigation leads to increased ET, and hence its totals values. For experimental conditions, with the improvement of water regime in irrigation variants, there is a growing influence of meteorological factors, very well expressed in variants with irrigation rate of 150%. There ET is over two times higher than non-irrigated variant in two of the experimental years. Evapotranspiration for irrigation by 50% of the estimated optimal irrigation rate is influenced less by temperature conditions, and its increase compared to non-irrigated sunflower in different years ranged from 26.5 to 36.5% (average 33.1%). Changes are relatively constant for the optimal variant, with the average relative increase of 67%. The increase in the extreme 2007 (46%) is the smallest due to high absolute values

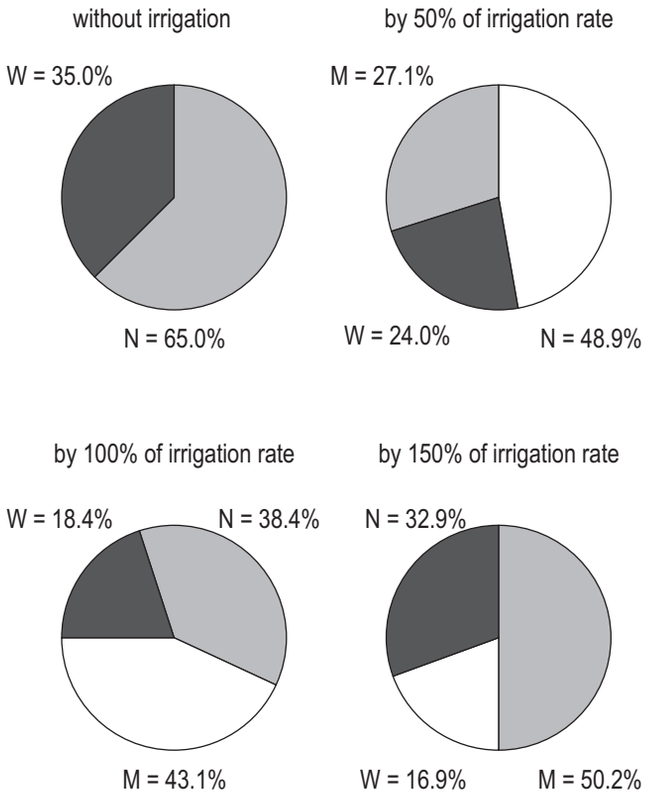
of ET in non-irrigated variant, on the one hand, and because the irrigation period begins only at the end of the period of full flowering and growth of the flower head and the number of irrigations is one less. In the first experimental year the results are similar with two irrigations as well, respectively at the end of flowering and during the period of seed-fill. Given the results in Table 2 we can make two main conclusions: 1) the impact of weather conditions during the year is more important for the change of absolute values of ET, depending on the water reserves; 2) as for the relative change of ET in different levels of water reserve, it is substantially influenced by the biology of the crop, so they vary within smaller borders in years with different characteristics. In support of this opinion are the graphs presented in Figure 1, which depicts the relative change of total ET with increasing relative irrigation rate, respectively, by year and average for the period of the experiment.

Experimental data points for all experimental years are approximated by curves of second degree representing convex parabolas, and accuracy is very high ($R^2 > 0.95$). The graph of Figure 1 is intended rather to illustrate the small fluctuation of the relative change of ET than to propose specific equations satisfying specific relation to each of the experimental years. Figure 2 gives average values separately for all experimental points and their average values with second-degree curves that almost coincide. The coefficient of determination for approximation of all points is very high ($R^2 = 0.934$), which makes the correlation reliable, and each of the two equations could be used for estimating the evapotranspiration of sunflower in soil and climatic conditions similar to those where this experiment was conducted.

Formation of Sunflower Evapotranspiration

Formation of evapotranspiration for rainfed sunflower happens mainly at the expense of vegetation rainfalls and initial water reserves accrued in the active soil layer in the autumn-winter and early-spring period. In irrigation conditions, irrigation norms have their respective share in formation of ET. The percentage distribution of components forming evapotranspiration depends mainly on the type of year as well as on the elements of applied irrigation regime. Detailed data for this characteristic are presented in Table 2.

In the conditions of this experiment rainfalls represent from 49.3 to 82.1% of ET of rainfed sunflower and what is significant in this case is not only their quantity but also their distribution, i.e. their



W – primary water supply; N – precipitations; M – irrigation depth;

Figure 2. ET formation – average for experimental period

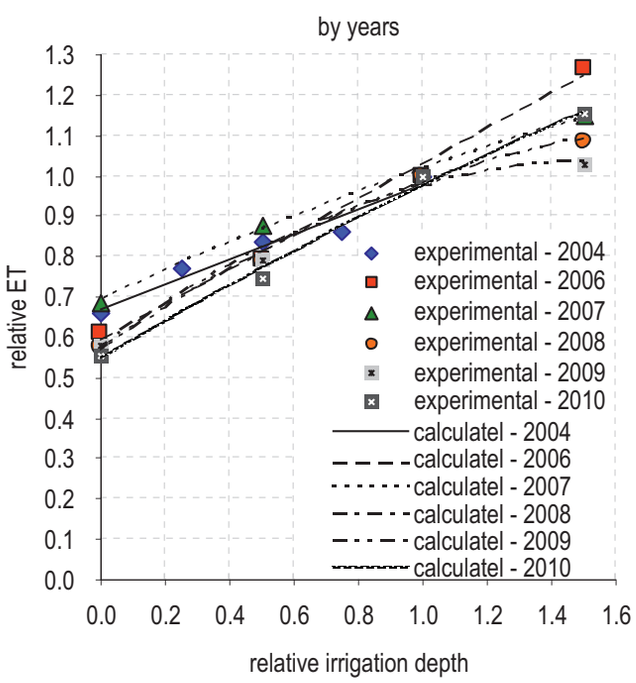
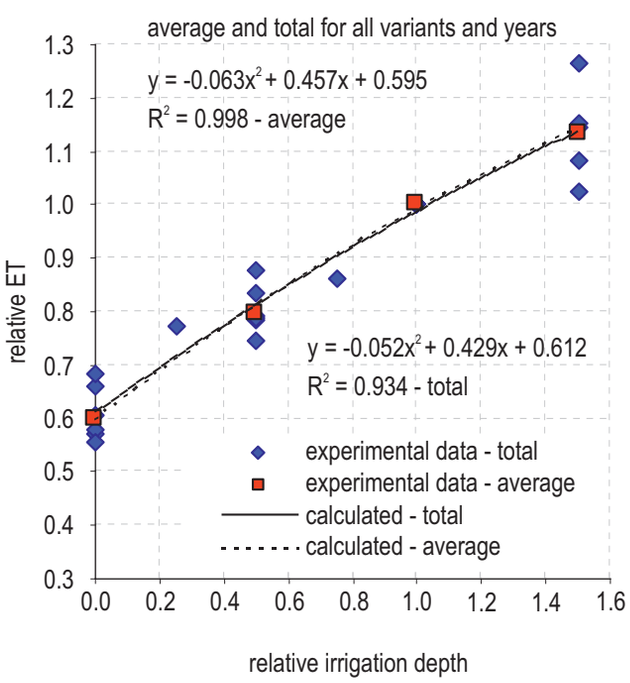


Figure 1. Relationship "Irrigation depth-ET"



consumption in the area of the active soil layer. With improvement of water regime in irrigated variants, percentage share of rainfalls drops. The bigger the percentage of irrigation norm, the smaller their share, and this is valid for each of the years. In irrigation with a norm of 50%, the percentage of rainfalls drops with an average of 16.1%, and by years it varies from 9.2 до 18.1%, though absolute values coincide. In this variant the respective share of rainfalls in ET is from 36 to 64% by years, with an average value for the experimental period – 48.9%. In the optimal variant consumed rainfalls decrease with an average of 26.6% as compared with the ones for rainfed sunflower and here there is already a change in absolute values with 2.5 mm. Here rainfalls by years are from 28 to 56% of the total water consumption and their average share for the experimental period is 38.4%. The smallest share in the total ET of layer 0 – 80 cm is for rainfalls in the variant with increased irrigation norm. For the first three years of the experiment the change is only in relative percentage values because of rise of the absolute ET while in the second three years there is also a drop in absolute values of rainfalls for this irrigation regime. As an average value for the experimental period, with increase in the irrigation norm with 50% as compared with the optimal one, rainfalls form 32.9% of ET of sunflower in layer 0 – 80 cm, i.e. the difference with the optimal variant is 5.5%. Figure 2 presents relative share of separate components forming evapotranspiration of sunflower for the separate variants, with average values for the experimental period.

Autumn-winter and early-spring moisture reserves have a smaller share in formation of ET as compared with rainfalls but depending on moisture conditions they change in the same logical sequence, i.e. the highest percentage is for rainfed sunflower and in 2008 it even exceeds rainfall share. Irrigation with a norm smaller than the calculated one in the optimal variant partially moisturizes the active soil layer by reason of which in case of lack of significant rainfalls about the date of irrigation there are conditions for consumption of residual moisture from the lower parts of the root soil layer. For this reason the share of this water reserve for irrigation with 50% of the norm is relatively high and its average value for the six years is about ¼ of the total ET. Variation in the years is from 17 to 33%. By increase in the amount of irrigation the relative share of the initial water reserve drops even more and in the optimal variant it is already 18.4%. Variation in the years is within a smaller range – from 13.5 to 22.7%. What is typical of the optimally irrigated variant is that with realization of the first irrigation the whole active soil layer forms its water reserve and from this moment ET is formed only by rainfalls and by irrigation norm, i.e. in case of lack of abundant rainfall (equal to one irrigation) the percentage share of the initial water reserve depends mostly on the time of first irrigation. Increase in the amount of the irrigation norm with another 50% does not change values significantly and, in average values, drop in the percentage share decreases with 1.5% as compared with the values of the optimal variant.

The results from all researches till the present moment show that in the weather conditions of Bulgaria irrigation norm has a significant share in the total ET of sunflower. The experiment carried out in Plovdiv district confirms this opinion and, except for 2007 when irrigation in the optimal variant formed 25% of ET, in the other five years variation is from 43.4 to 49.1% (average value of 43.1%). In contrast with rainfalls and initial water reserves, with reduction of the amount of irrigation norms, their relative share in ET formation also drops. However, we notice that there is a more significant increase of the percentage share of the irrigation norm in the variant with norm of 150% as compared with the optimal variant. Most probably the reason for this is the defect in the weighing method for measuring soil moisture, in view of the fact that from the time of taking soil samples till results are received and irrigation is realized, water reserves in the tested soil layer may practically drop with another 10 – 20 mm. In these conditions we need a norm higher than the optimally calculated norm in order to reach FC (Field Capacity). In practice this happens by increasing the norm (in a variant of 150%), providing maximal moisture for the active soil layer. According to the results from the experiment, the excessive quantity of the irrigation norm in this variant moves to the layer of 80 – 100 cm. Carrying out three vegetation irrigations in these conditions leads to water deficit in the optimal variant and its average value for the experimental period is about 70 mm, i.e. if the average irrigation norm for variant 100% m is 222.3 mm, the maximal actually used irrigation water is 293.6 mm, provided by variant 150% m.

Trend of daily evapotranspiration

For the purposes of irrigation, beside the total ET, ET for the separate periods of crop development is also very important. Till the phase of bud formation, sunflower's water consumption is relatively small because air temperature is still low and it has smaller evaporation leaf surface. With the beginning of the reproduction period the daily ET of sunflowers starts to increase significantly and during the period of mass flowering and growth of flower heads it reaches its maximal values which, in case of optimal irrigation, frequently remain the same till the end of seeds fill. Although environment conditions do not change significantly, during the period of seeds ripening the values of daily water consumption start to gradually decrease because of leaf aging and slowing down of intensity of vital processes. Irrespective of this, they remain quite high and their preservation through provision of enough quantity of easily accessible soil moisture is of significant importance for yield. After completion of this phenophase, intensity of ET sharply decreases and during the period of ripening it has values similar to the ones from the beginning of vegetation.

Apart from depending on the biological characteristics of the crop, connected with the specific features of the separate phenophases with respect to water requirements, the trend of daily ET for sunflower is significantly influenced by the nature of the year as well as by the used irrigation regime. Figures 3, 4, 5, 6, 7 and 8 clearly show the values of ET during all six experiment years and for all tested variants.

During the first experimental year rainfalls are equally distributed during vegetation, though their quantity rarely exceeds 10 mm. Under these conditions, till the beginning of flowering ET is absolutely guaranteed in a natural way, by reason of which the maximum for the rainfed variant is relatively high and it is in the first ten days of July during the period of mass flowering and formation of flower heads. The relatively high deficiency of air humidity under these conditions also contributes to more intensive water consumption. In the conditions of the respective year, irrigation delays the maximum of ET with ten days for variants with low irrigation norms (25 and 50% m), and in case of 75% of the irrigation norm it also occurs in the second ten days of July but continues to keep the same values in the next ten days when the maximum of the optimal variant occurs.

The conditions during the second experimental year (2006) completely and in a natural way ensure the water consumption of sunflowers till bud formation, after which there was a short-term drought. In spite of this, soil moisture does not drop significantly below the easily accessible one, by reason of which in the rainfed variant ET intensity continues to increase. In the first ten days of July in the period of mass flowering there is a total of 94 mm rainfall which

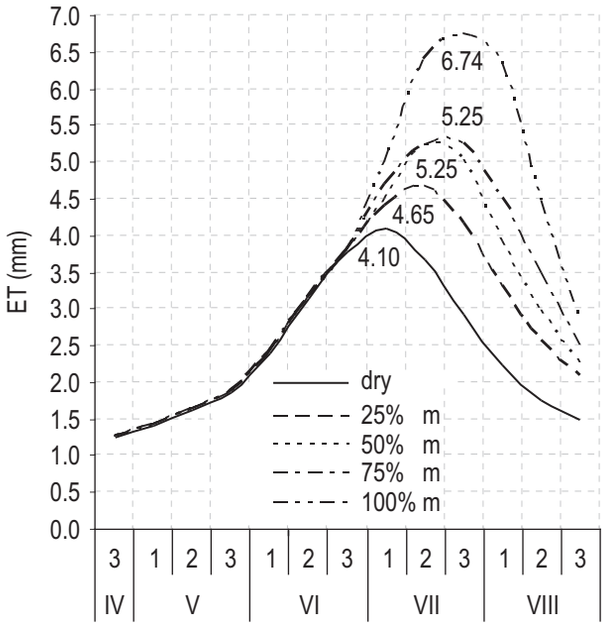


Figure 3. Trend of daily ET during 2004

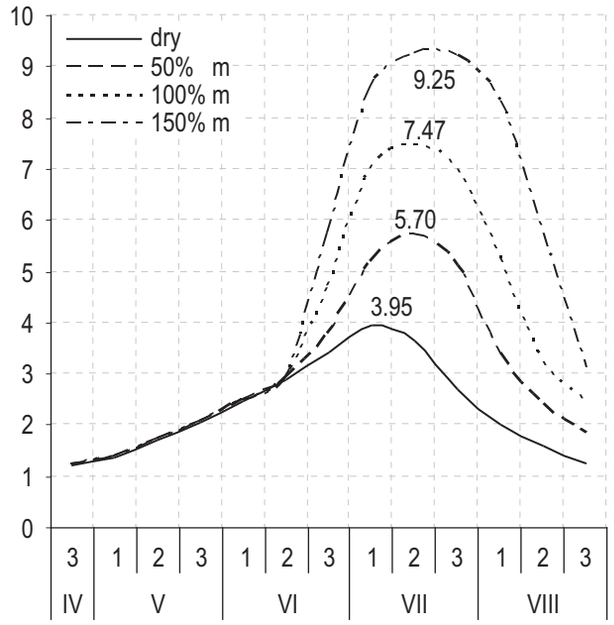


Figure 4. Trend of daily ET during 2006

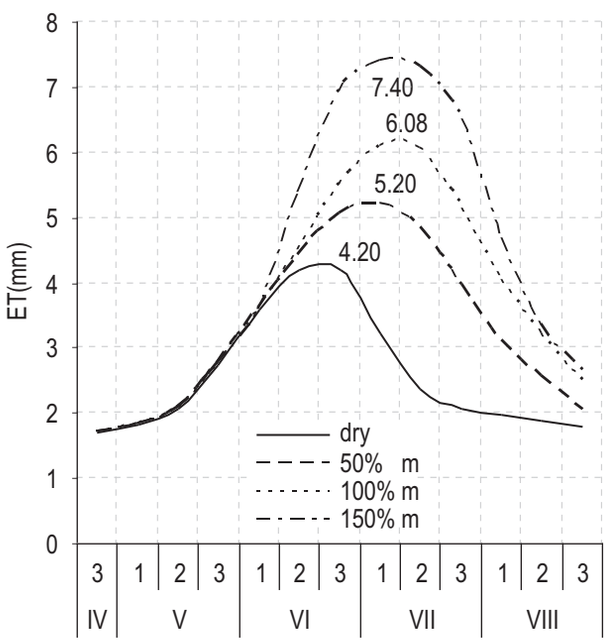


Figure 5. Trend of daily ET during 2007

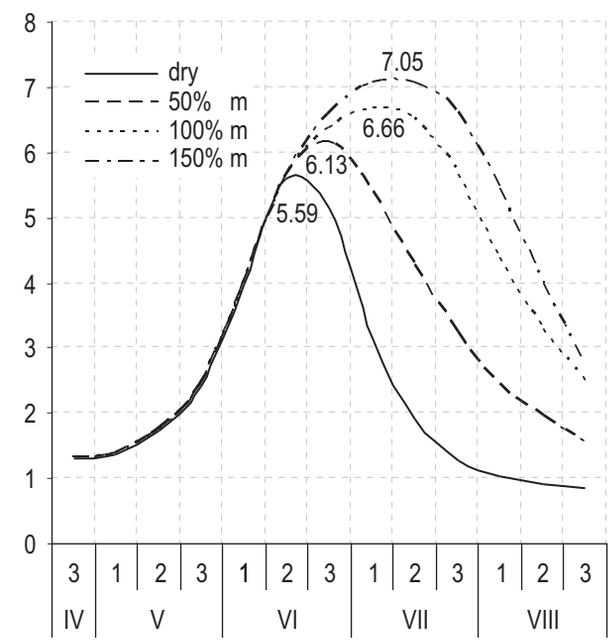


Figure 6. Trend of daily ET during 2008

to a great extent normalize water regime in the active soil layer of rainfed sunflower. Then the maximal average daily values of ET (3.9 mm) are reached. However, after that, till the end of vegetation there is almost no rainfall by reason of which intensity of water consumption starts to decrease fast. As the year is favourable in terms of temperature and air moisture deficiency, the irrigated variants create conditions for very intensive water consumption. The irrigation in the second ten days of July, rainfall at the beginning of July and a second irrigation in the middle of the month (growth of the flower head and formation of seeds) lead to sharp increase in average daily values to 5.7 mm with an irrigation rate of 50%, 7.5 mm in the optimal variant and extremely high values of 9.2 mm in the variant irrigated with irrigation rate of 150%. The maximum in irrigated variants, as distinguished from the previous year, is delayed with only ten days and in the variant with highest irrigation norm it keeps levels above 9 mm in the third ten days of July, too.

The vegetation period of sunflower in 2007 is characterized by constant changes in weather conditions. Rainfalls completely ensure water consumption till the phase of full flowering and growth of flower heads (the third ten days of June). The drought that started as early as the second ten days of the month continues till the end of July and as early as the middle of the month the daily ET of rainfed sunflower drops to its initial values. Because there is enough quantity of easily accessible soil moisture, the maximum remains for two periods of ten days (the second and third one of July). The two irrigations, respectively in the period of mass flowering and growth of flower heads and the period of seeds ripening, combined with the significantly higher than the normal values of temperature and

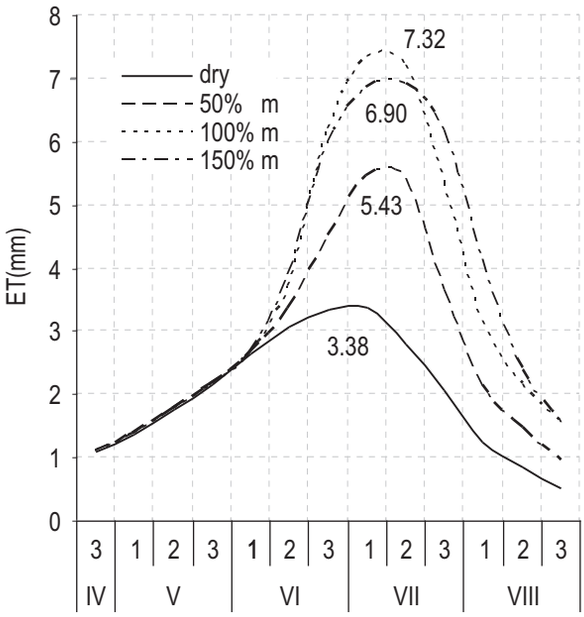


Figure 7. Trend of daily ET during 2009

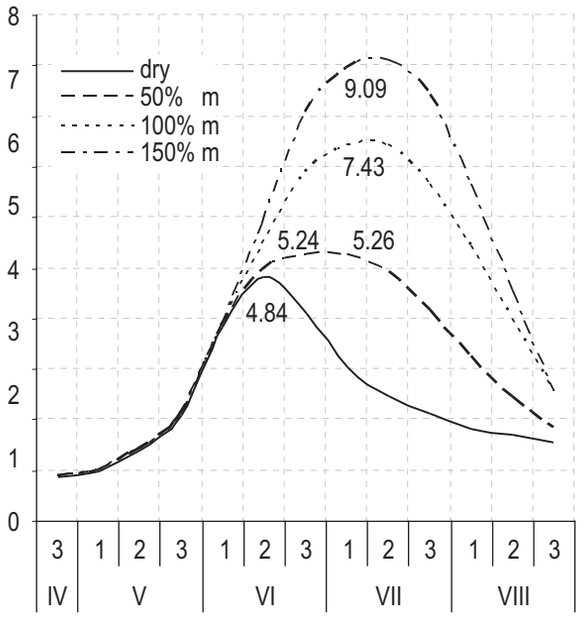


Figure 8. Trend of daily ET during 2010

deficiency of air moisture, lead to a sharp increase in water consumption intensity. Even in the variant irrigated with 50% of the irrigation depth, the maximum comes about two periods of ten days later, and in more favourable years this happens maximally ten days later. In the variants with high irrigation rates the two irrigations optimize soil moisture by reason of which evapotranspiration reaches the values typical for the crop. For the optimal variant, the maximum is 6.1 mm and is in the period of seeds fill, keeping approximately the same values for about two periods of ten days (the first and second ones of July). In case of increased irrigation norm the difference is only in the 1.2 – 1.3 mm higher values (Figure 5).

Favourable distribution of rainfalls, in combination with high values of the initial water reserves in 2008, ensure water consumption till the phase of bud formation. In this experimental year sowing was carried out on 30 April, therefore the vegetation period of sunflower vegetation proceeds in relatively higher temperatures. As seen in Figure 10, this has affected daily values of ET for the rainfed variant which, as distinguished from the other years, are with higher maximum (5.6 mm) registered in the second ten days of June at the beginning of the phase of bud formation. Because of the drought after that, continuing till the end of vegetation, intensity of ET in the rainfed variant starts to drop sharply, though the plants proceed to the next phases, characterized by high water consumption. In the period of seeds fill values are even lower than the initial ones, irrespective of the fact that the dates of this period coincide with the first and second ten days of August when pressure of weather factors is significantly high. With the improvement of water regime in irrigated variants, as in the other years, evapotranspiration has higher values and is delayed in time. In the variant irrigated with a norm of 50%, in this experimental year there is a maximum of 6.13 mm, which is the highest value in this variant for all experimental years but is also earliest in time and as a phase of occurrence – the third ten days of June, in the phase of bud formation. Because of the fact that in lack of rainfalls small irrigation norms cannot keep high values of water consumption, the same starts to drop as early as flowering starts. Flowering ends with values below 5 mm per 24 hours and during seeds fill it is within the range of 3.0 – 3.5 mm. In the variant with optimal irrigation and the variant with increased irrigation norm there is the already established correlations between time, phenophase and maximal values of ET. In the variant with a norm of 150%, maximal values continue for a period of extra ten days (the first and second ten days of July), till the beginning of seeds fill and the values are about and above 7 mm for 24 hours. At the end of this period (the second half of August), optimally irrigated sunflower consumes 3 – 4 mm water for 24 hours.

The experimental 2009 is characterized as moderately dry with respect to rainfall but it is actually the driest of all experimental years. It is characterized by a more significant late spring drought during the period of sunflower growth. By reason of this, the graph of ET for rainfed sunflower shows a slow rise and reaches a maximum of only 3.4 mm in the period of massive flowering and growth of flower heads. By the end of flowering and the beginning of seeds fill the values start to decrease very intensively and at the end of vegetation they are less than 1 mm for 24 hours. In irrigated variants maximums start almost at the same time (the beginning of the period of seeds fill), and the values increase with increase in the size of the norm and are not significantly different from the ones established in the previous years (Figure 7).

Figure 8 shows the trend of daily sunflower ET in the last experimental (2010) year. The initial water reserves and vegetation rainfalls ensure optimal water consumption till the middle of June (the beginning of the phase of bud formation). The course of the curve describing the change in its values till the middle of June is significantly more steep than the one of the previous year not only because of the better natural provision of moisture for the crops but also because of the favourable influence of the other two meteorological factors which had values similar to the norm during almost the whole period of sunflower vegetation. For irrigated variants there is an extremely favourable shift between significant rainfalls with vegetation irrigations, that is why the maximum for a variant of 50% m remains more than 5 mm for 24 hours for about a month (till the beginning of seeds fill). For variants of 100 and 150% m, because of high irrigation norms, ET reaches the values maximally possible for the crop in the period „end of flowering-

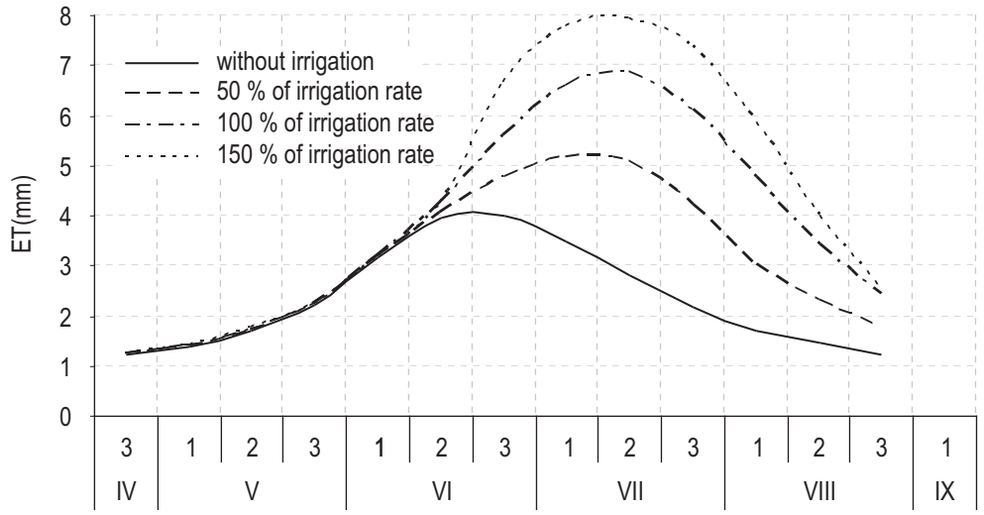


Figure 9. Trend of daily ET of sunflower by decades (average for experimental period)

beginning of seeds fill". For the optimal variant during the whole reproductive period evapotranspiration is higher than 6 mm for 24 hours and only at the beginning of the period of seeds fill it decreases to 3 – 4 mm. The difference between the two variants varies from 1.0 to 1.5 mm from the beginning of flowering till about the middle of the period of seeds fill, after which it starts to decrease and by the end of August it practically does not exist.

Figure 9 presents trend of daily ET of sunflower by using the average results from the six experimental years. Analyzing the resulting graph leads us to the following significant findings:

• Average 24-hour values of ET for rainfed sunflower increase till the beginning of the irrigation season, i.e. till exhaustion of the easily accessible moisture in the active soil layer. This happens most often during the phases of bud formation or the beginning of flowering, with calendar dates coinciding with the second and third ten days of June. For the conditions of the experiment, the maximum for this variant is an average of 4 mm for 24 hours.

• Irrigation influences the values of ET, on one hand it increases values (depending on the degree of water reserves) and changes the time when the maximum starts by increasing its period at the same time. For the conditions of the experiment, with irrigation of 50% of the irrigation depth calculated for the optimal variant, the maximum is in the first and second ten days of July which usually coincides with the massive flowering and growth of flower heads.

Table 3. Crop water use productivity of sunflowers depending on irrigation regime

Variants	ET (mm)	Yield kg/ha	ET productivity 1	ET productivity 2	ET (mm)	Yield kg/ha	ET productivity 1	ET productivity 2
		2004				2004		
no irrigated	330.8	1176	0.281	3.555	302.4	1576	0.192	5.212
25% m	385.4	1341	0.287	3.480				
50% m	417.2	1833	0.228	4.394	394.6	1985	0.199	5.030
75% m	431.5	2077	0.208	4.813				
100% m	499.9	2132	0.234	4.265	498.0	2303	0.216	4.624
150% m					630.9	2234	0.282	3.541
		2007				2008		
no irrigated	341.7	1229	0.278	3.597	313.4	2057	0.152	6.563
50% m	437.5	1873	0.234	4.281	430.5	2680	0.161	6.225
100% m	498.5	2274	0.219	4.562	547.6	3019	0.181	5.513
150% m	571.6	2316	0.247	4.052	592.8	2944	0.201	4.966
		2009				2010		
no irrigated	274.4	1698	0.162	6.188	311.0	2071	0.150	6.659
50% m	374.5	2911	0.129	7.773	416.4	3597	0.116	8.638
100% m	474.7	3334	0.142	7.023	558.6	4074	0.137	7.293
150% m	486.8	3149	0.155	6.469	643.3	4072	0.158	6.330

*m – irrigation rate

The average absolute values of the maximum in this variant are 5.1 – 5.2 mm. During the period of seeds fill the average water consumption is between 3 and 4 mm per 24 hours and at the end of vegetation it is about and below 2 mm. With optimal irrigation the values are significantly higher; the maximum is in the second ten days of July and it is 6.8 mm per 24 hours. It is above 6 mm for three periods of ten days (all July), and above 5 mm per 24 hours for about a month and a half. High daily values in case of irrigation with increased irrigation norm (150% m) have longer periods and are above 7 mm from the end of June (bud formation) till the end of July (seeds fill). The maximal average daily water consumption in this variant is also in the second ten days of July and is an average of 7.9 mm for 24 hours. Irrigation lengthens the life of sunflower leaves and the more favourable the water and air regime is for the soil, the longer the life of leaves is. For the different variants of the experiment, the period of work of the crop canopy is different and in spite of the fact that in general the leaves begin to get old, transpiration is preserved as their function. On the other hand, after finishing the irrigation period till the end of vegetation, the available water reserves are different for the separate variants of the experiment. In these conditions the intensity of ET in the after-irrigated period is different and the differences between the variants are preserved till the end of vegetation.

Evapotranspiration productivity

Table 3 shows by years and variants the results for productivity of evapotranspiration for sunflower in Plovdiv district. As it was mentioned in the methodology part, assessment of effectiveness of water consumption may be done in two aspects, namely: evapotranspiration (mm), necessary to receive a yield of 1 kg/ha; yield (kg/ha) received from 1 mm consumed water. For rainfed sunflower, there is great variation of water consumption values for getting a yield of 1 kg/ha in each separate year. This results from the strong influence of the specific characteristics of the respective year, on yield as well as on total evapotranspiration. During separate years effectiveness of water consumption in this respect is from 0.150 to 0.281 mm for a yield of 1 kg/ha. There is certain regularity for irrigated variants. Because of stronger influence of irrigation regime on yield than on ET, in case of irrigation with 50% of the norm the quantity of water necessary for one unit of yield is the smallest. For the optimal variant, values increase and for the variant with a norm of 150% they are the highest because yields remain the same and at the same time ET is the highest. Viewed as yield from 1 mm water consumption, the tendency is the other way round, with the lowest irrigation values for 150% of the norm for the optimal variant. Reduction of irrigation norm increases values and they are the highest with irrigation of 50% of the irrigation norm.

Conclusions

The seasonal evapotranspiration of sunflower is affected by the meteorological conditions in the respective year and in rainfed conditions it varies from 274 to 342 mm (an average of 309 mm). Irrigation with 50% of the optimal irrigation depth increases ET with an average of 33.1% and in different years it varies from 26.1 to 37.4%. The optimally irrigated sunflower uses from 475 to 559 mm (an average of 516 mm). Increase of ET as compared with the rainfed sunflower is an average of 67%. In case of irrigation with 150% of the irrigation depth ET increases with extra 2.5 – 26.7% (an average of 13.5%).

• There is very close interrelation between the relative irrigation norm and the relative total evapotranspiration that is successfully expressed by the quadratic equation $Y = – 0.063x^2 + 0.457x + 0.595$, where the free member of the equation represents the relative ET in rainfed conditions. The interrelation graphically represents a convex parabola approximating experimental data with $R^2 = 0.998$.

Evapotranspiration of the rainfed sunflower is formed by autumn and winter moisture reserves and vegetation rainfalls. In irrigation conditions, the irrigation norm takes its respective share, depending on its values. With increase in the values of the irrigation norm, the respective share of rainfalls and the initial water reserves decrease. ET of sunflower was formed in the following way for the conditions of the experiment:

- In rain-fed conditions, the relative share of vegetation rainfalls is an average of 65% (from 49 to 82%), and for the initial water reserves – 35% (from 18 to 51%);
- In case of irrigation with a norm of 50% the share of rainfalls is an average of 49% (from 36 to 64%), for the initial water reserves it is 24% (from 17 to 33%), and the irrigation norm – 27% (from 14 to 31%);
- In case of optimal irrigation (norm 100%) the share of rainfalls is an average of 38% (from 28 to 56%), for the initial water reserves it is 19% (from 16 to 23%), and the irrigation norm – 43% (from 25 to 49%);
- In case of irrigation with increased norm (150%) the share of rainfalls is an average of 33% (from 26 to 49%), for the initial water reserves it is 17% (from 15 to 18%), and the irrigation norm – 50% (from 32 to 56%).

The maximum value of daily ET for rainfed sunflower is an average of 4 mm, varying from 3.3 to 5.6 mm by years. In its phenological aspect the maximal value coincides with the period of bud formation – the beginning of flowering and in its calendar aspect – with the second half of June. Irrigation with norm of 50% increases values of ET to 5.2 – 6.1 mm. The maximal value of this regime of irrigation is most often ten days later, in the period of mass flowering – increase of the flower head. In case of optimal irrigation the maximal values of daily ET will remain the same usually to the beginning of phase „seeds fill", and the values are between 6 and 7 mm. Increase of irrigation norm with 50% as compared with the optimal one leads to increase in the maximal values of ET to 7 – 9 mm, and as for time they coincide with the ones in the optimal variant.

Water consumption is most effective with irrigation with irrigation depth of 50%, and in order to get 1 kg/ha yield, an average of 0.166 mm water is used, for 1 mm water consumption the yield is 6.02 kg/ha.

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