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EVAPOTRANSPIRATION OF SOYBEAN, GROWING AT DIFFERENT IRRIGATION REGIME

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Abstract

The aim of the research is establishment of soil moisture level influences on the evapotranspiration (ET) and water use efficiency (WUE) of soybean. The field experiment was conducted in period 2009-2010. Three treatments were applied: T1 without irrigation, T2 irrigation at 80% of field capacity for the soil layer 0-0.6 m, T3 irrigation at 90% of field capacity. Evapotranspiration of soybean under rain-fed conditions is 272 mm. In irrigation regime T2ET increases by 50% and in irrigation regime T3 - by 63%, respectively 407 and 443 mm. The maximum ET daily values were observed during period of flowering and bean forming. During the same period 48-49% of ET is formed, irrespective of irrigation regime. Soybean consumes the most intense water from the layer 0-0.2 m (more than 20%). The total irrigation rate provides 50-52% for ET of T2 and 55-56% for T3. Water use efficiency is higher at lower soil moisture (80% of FC) - 1.843 kg/m^3, while at 90% of FC WUE is 1.856 kg/m^3. It is recommends irrigation, when soil moisture drops to 80% of the field capacity.

Key words*: soybean, evapotranspiration, water use efficiency.*

INTRODUCTION

The question of establishing a biologically optimal and economically justifiable crop irrigation regime has been on the agenda for several decades. An integral part of the research in this direction is related to the study of evapotranspiration at different levels of water supply, focusing on the establishment of the total and daily average values. Knowledge of its formation is required to predict irrigation and establish an appropriate irrigation regime. Comparative studies to determine the influence of the soil moisture level before irrigation on soybean ET are in the range between 60 and 80% FC, since within these limits are the biologically optimal and economically justified irrigation regimes (Gorbanov, 1977; Eneva & Valchanov, 1986; Dimitrova & Dimitrov, 1987; Chervenkova & Matev, 2005). Maintaining excess soil moisture above 80% of FC according to Dimitrova & Dimitrov (1987) is justified when soybeans are cultivated for green mass. The data presented by Matev & Zhivkov (2005) and Georgiev et al. (2009) for central northern Bulgaria and by Zhivkov & Matev (2004) - for the Sofia region are similar. The use of drip irrigation in major arable crops (including soybean) has increased significantly over the last decade. In the specialized scientific literature for drip irrigated soybean, limits of pre-irrigation soil moisture in the range of 70-80% FC are proposed (Pavlenko et al., 2010; Shuravilin et al., 2009; 2015; Borodychev et al., 2008; Babayan, 2018).
The purpose of this study is to establish soybean evapotranspiration under optimal and intensive irrigation conditions and to evaluate its effectiveness.

MATERIALS AND METHODS

During the period 2009-2010, a field experiment was conducted in the Agricultural University of Plovdiv on an alluvial-meadow soil. Three treatments were applied: T1 rain-fed only - control; T2 irrigation at 80% of FC; T3 irrigation at 90% of FC. The soil moisture was monitored by gravimetric method (every 0.10 m) to a depth of 1 m. Evapotranspiration is determined by water balance calculations, To determine its distribution during the growing season, it is conditionally divided into three periods, with the I period covering the time from sowing to the beginning of flowering. , II period is the period of flowering and bean-forming, and IIIth is the period of grain filling. Irrigation was carried out using a drip system, with a dripper's distance of 0.30 m. The experiment is based on the method of long plots in three repetitions, with the size of the experimental plot of 40 m^2, and of the harvest plots - 14 m^2. The middle-grade Bulgarian Srebrina variety was used.

RESULTS AND DISCUSSIONS

The meteorological parameters of the year influence the evapotranspiration (ET) and the elements of the irrigation regime. The first year (2009) was considered as an average dry in terms of rainfall of 190 mm/69% security), while 2010 is an average with security of 52% and rainfall of 234 mm. The distribution of rainfall during the first experimental year was uneven, when from mid-July to the end of August, rainfall is only 20 mm. In the second year of experience, the situation is more favourable. In addition to the significant quantities, there is a large number and rainfall of up to 5 mm, which also have a positive effect on the microclimate of the crop and on the intensity of ET. In terms of air temperature, the two experimental years are favourable for the normal development of soybean plants. Under these conditions irrigation practice is necessary in order to keep soil moisture above 80% of FC. The irrigations rates applied are shown in Table 1.

Table 1. Irrigation rates IR, mm

Number	T2 80% of FC		T3 90% of FC	
	period	mm	period	mm
2009				
1	II	55.1	II	32.1
2	II	44.4	II	25.5
3	III	57.5	II	45.1
4	III	59.2	II	31.2
5	-	-	III	44.4
6	-	-	III	60.0
IRaverage		54.1		39.7
IR total		216.2		238.3
2010				
1	II	66.0	II	66.0
2	II	39.0	II	26.0
3	III	49.0	II	23.0
4	III	47.5	II	25.0
5	-		III	15.0
6	-		III	25.0
7	-		III	25.0
IRaverage		50.4		29.3
IR total		201.5		205.0

Maintaining soil moisture up of 80% of FC for the experimental conditions was accomplished with 4 irrigations with an average irrigation rate of 52 mm. The irrigation period in this variant includes the time from the beginning of flowering to the filling of the grain, i.e. the whole reproductive period.

At higher soil moisture (90% of FC) the number of irrigation is 6-7, but with lower irrigation rates. The difference between the irrigation rates at T2 and T3 ranges from 26 to 42%. The irrigation period for this variant of irrigation is longer, because it starts about a decade earlier, and the inter-irrigation period is much shorter. The difference in total irrigation rate for the two treatments is in the range of 2-10%.

Evapotranspiration for growing season

Irrigation is a major factor influencing the values of evapotranspiration ET, according to Eneva (1986) under non-irrigation conditions ET reaches 250 mm and under optimal irrigation (up to 80% FC) it increases significantly and reaches 580-590 mm. Lower are the values stated by Mayaki et al. (1976). Dimitrova & Dimitrov (1987) and Chervenkova & Matev (2005) - between 460 and 500 mm. Studying the ET of soybean irrigation on the basis of different soil moisture levels, Kravchuk et al. (2015) find that ET is maximum (415 mm) when applying a 70-80-70% FC irrigation scheme. In the range of 60-80% of FC, ET of soybeans reaches 475 mm (Just et al., 2017).

The total ET data for the conditions of this experiment are presented in Table 2.

Table 2. Evapotranspiration ET for growing season

Treat ment	ET (mm)	to rain fed		to 80% FC		to 90% FC	
		± mm	%	± mm	%	± mm	%
2009							
T1	260.9	st	100.0	-153.4	63.0	-172.9	60.1
T2	414.3	153.4	158.8	st	100.0	-19.5	95.5
T3	433.8	172.9	166.3	19.5	104.7	st	100.
2010							
T1	282.0	st	100.0	-117.9	70.5	-169.1	62.5
T2	399.9	117.9	141.8	st	100.0	-51.2	88.6
T3	451.1	169.1	160.0	51.2	112.8	st	100.
Average for 2009-2010 period							
T1	271.5	st	100.0	-135.7	66.7	-171.0	61.4
T2	407.1	135.7	150.0	st	100.0	-35.4	92.0
T3	442.5	171.0	163.0	35.4	108.7	st	100.

For non-irrigated soybean, ET reaches 261 mm during the average dry year 2009 and 282 mm in 2010. Higher values in the second year are due to better natural water supply to the plants, but the difference from the previous year is relatively small, due to the very frequent and low rainfall, which reduce the tension of weather factors, increase the humidity of the ground layer air and reduce the intensity of ET. Irrigation applied to keep soil moisture above 80% of FC increases water consumption by an average of 50%. In the drier 2009, ET under non-irrigation conditions is 63% comparing with T2, and in the more favorable 2010 - 70.5%. Keeping soil moisture up to 90% FC increases the soybean water consumption between 5 and 13% (average 8.7%), reaching values 434 and 451 mm. At 90% FC easily accessible water is more, which is a prerequisite for its intensive consumption, but on the other hand, the greater number of irrigations increases the duration of the period during which the surface soil layer is humidly close to the FC. Under these conditions, evaporation from the soil surface is increasing, and it is an integral part of ET.

Evapotranspiration by periods

The values of total ET give a general idea of the water needs of the plants throughout the growing season. However, it has been proven that, under equal conditions, the plants consume water at different intensities during the different phases of the growing season. According to researches by Gorbanov (1977), from the emergence to the beginning of flowering ET of soybeans is from 90 to 110 mm, and for the whole period of flowering and bean formation between 300 and 330 mm. From the end of flowering to the harvest, the ET moves in the range of 70-110 mm. These values and deadlines depends of crop water supplies, soil depth, irrigation methods etc.

For the conditions of this study, the data of evapotranspiration, presented in Figures 1 and 2 are valid for the 0-0.60 m soil layer (in absolute and relative values, respectively). Under non-irrigation conditions, during the I period, average value of soybean ET is 70 mm, varying from 60 to 80 mm.

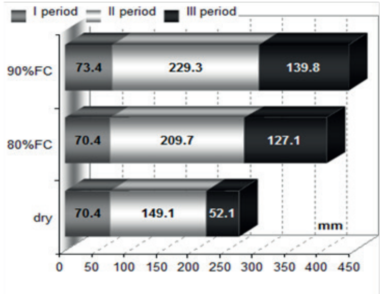

Figure 1. Evapotranspiration of soybean upon periods of vegetation, in mm

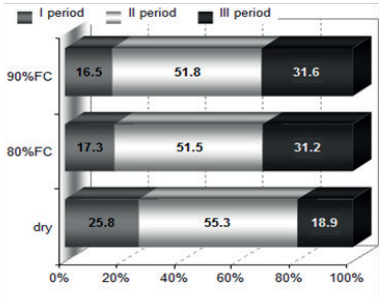

Figure 2. Evapotranspiration in relative values upon periods of vegetation, in %

This period is of long duration (between 4 and 5 decades), but due to the smaller leaf area and less pressure of meteorological factors, the relative ET is on average 26%, varying between 23 and 29%. The same results are received for the ET during this first period of crop vegetation for the irrigated treatments, because of high soil moisture level and lack of irrigation. The flowering and beaning period is critical to the soybean requirements for water and, at the same time, falls calendar-wise into the hottest and often driest part of the year (from the second half of June to the end of July). Under these conditions, easily accessible water in the active soil layer depletes rapidly, which limits the intensity of ET, especially in the absence of rainfall. Therefore, ET under non-irrigation conditions is relatively low - between 130 and 170 mm (average 150 mm. The relative share of the second period is high (46-65%) against the background of relatively low absolute values. Compensating for the deficit of rainfall, irrigation leads to an increase in the intensity of ET, while maintaining a soil moisture up of 80% FC. Its absolute values during the flowering and bean-forming period are in the range 205-215mm. This means that irrigation only increases ET in the second period by an average of 40%, depending on the conditions of the year between 27 and 58%. This irrigation regime stabilizes the water supplies of the crop, there is no difference between the two experimental years and the relative share of the period amounts to 51-52%. Treatment T3 showed Et increasing between 4 and 15% (on average by 9.3% or by 20 mm. During this part of the growing season, soybean respond most strongly to the different levels of water supply. The differences in the absolute values of the ET between the two irrigation variants are proof of this. They are mostly due to the difference in the total ET. Evapotranspiration during the third period depends to a large extent on the water supply conditions of the previous two periods. For a period of 40-50 days an average of just over 50 mm is consumed under non-irrigation conditions; in the drier 2009, only 33 mm are spent, and in the wetter 2010, just over 70 mm. As a result, the relative ET during this period is low and averages 19%, varying between 13 and 25% over the years. In order to maintain soil moisture up of 80% FC, two irrigations were supplied during this period, as much as during the flowering and bean-forming period, and the environmental conditions also did not differ significantly. Nevertheless, the ET in this irrigation mode is 114-140 mm, ie. it decreased significantly compared to what was reported in the previous period. This is mainly due to the gradual attenuation of the processes in the plant organism leading to a decrease in water consumption. During this period, between 29 and 34% or approximately 1/3 of total ET is formed. At higher soil moisture (90% FC), irrigation during the grain filling period is 2-3. Thanks to them, ET increases by 8-12%, while maintaining the relative share within approximately the same limits (29-35%). These results show that during this phase soybeans respond positively to high soil moisture by increasing the amount of water consumed by 10-15 mm.

Daily average ET values depending on soil moisture

Information about the average daily ET values for soybean, establish in the same region, was published by Dimitrova & Dimitrov (1987) and Chervenkova & Matev (2005). The authors find that the maximum of 6.0-6.5 mm is during the period of mass flowering - bean formation. Selitsky (2002) establishes approximately the same values of ET, when applying a rational irrigation regime during flowering - bean filling it reaches over 5 mm. The author found that at the beginning and at the end of the growing season it was respectively 56 and 42% smaller. Figure 3 shows the average daily flow of ET depending on irrigation regime.

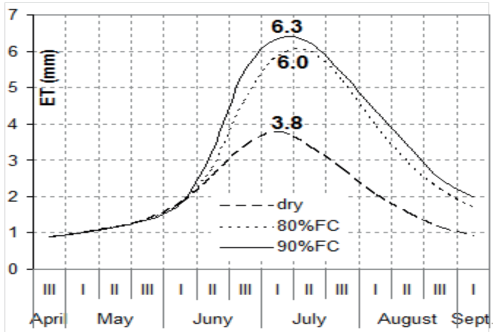

Figure 3. Daily average values of evapotranspiration for the season

In line with the distribution of ET by periods are also the results concerning the change of daily average values. Thus, under rain-fed conditions, the maximum of 3.8 mm per day is recorded in the first decade of July during the period of mass flowering, after which the values begin to decrease gradually. For the conditions of T2 ET increases very rapidly, reaching 4 mm per day at the beginning of the reproductive period, and a maximum of 6 mm in the second decade of July, confirming the outflow from other authors information. These high values are retained for about 1 ten days, after which the intensity of ET begins to gradually decrease, but remains significantly higher than that under non-irrigation conditions. When soil moisture was maintained to 90% of FC, the average daily ET values exceed those at T2 throughout the irrigation period. The maximum of 6.3 mm is also in the second decade of July, but values above 6 mm are retained for about 2 ten days (from 1 to 20 July). As the graph clearly shows, the most significant differences between the two irrigation regimes are in the second period of soybean growing. The differences between the two irrigation variants during the third period are smaller but remain relatively constant over time. Although our experimental years are extreme, under the irrigation conditions there is a characteristic shift of the ET maximum by about ten days later. During very dry years, this difference can be increased to 2 ten days for obvious reasons. Soil level moisture before irrigation does not affect the time of maximum occurrence.

Layer formation of ET, depending on the pre-humidity

The distribution of ET in depth (by soil layers) is influenced mainly by two factors. The first is the distance of a given soil layer from the surface, in connection with the possibility of influence of abiotic factors, as well as absorption of different amounts of water precipitation and irrigation. The second factor is based on the distribution of the root system in depth, on which the contribution of the given soil layer to the formation of ET largely depends. According to Mayaki, et al. (1976), in the 0-0.30 m layer 67% of the root system of non-irrigated soybean is placed, and more than 70%under irrigation conditions. Benjamin (2006), reported an even greater concentration of roots in the surface soil layer-about 97% of the soybean roots are located in the 0-0.23 m layer. According to Willatt & Olsson (1982), very small is the proportion of roots located at depths below 0.70 m. The authors found that the bulk of ET formed in the layer between 0.15 and 0.50 m, with water being reduced significantly below this depth, even when maintaining high soil moisture. The main reason is the small amount of roots. Figures 4 and 5 illustrate the layered formation of ET under non-irrigation conditions, as well as irrigation on the basis pre-irrigation soil moisture 80% and 90% of FC. The results generally confirm the information presented above by other authors, but at the same time they are specific in terms of soil and climatic conditions and variety specificity. Under non-irrigation conditions, the surface soil layer (0-20 cm) absorbs most of the rainfall, which is why over 50% of the ET is formed by it (Figure 4).

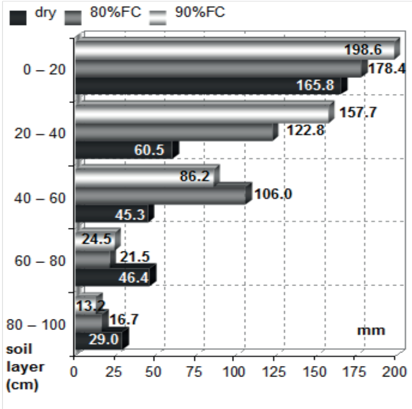

Figure 4. Layer formation of seasonal ET, in mm

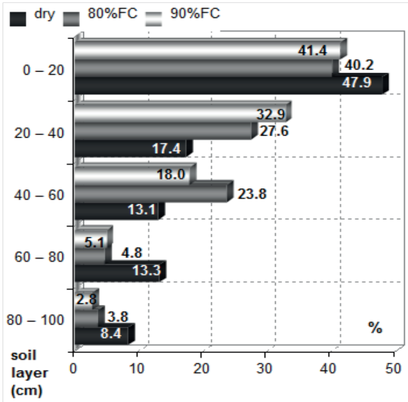

Figure 5. Layer formation of seasonal ET, in %

With increasing depth, ET in this variant decreases significantly, but in the 20-80 cm layer varies within relatively narrow limits (between 45 and 60 mm). Irrigation at soil moisture 90% FC is associated with the supply of more irrigations with lower irrigation rates, which is a prerequisite for higher water consumption from the 0-40 cm layer. Therefore, the ET of the 40-60 cm layer in this variant is inferior to 25% (average 20 mm), to the 80% FC. Because irrigation rates are calculated for wetting depths up to 60cm, there is practically no difference between the two irrigation options below this depth. Data on the relative distribution of water flow over soil layers shows that, regardless of water supply, more than 40% of ET is formed from water in soil layer 0-20 cm (Figure 5). In general, 80% of the total ET is formed in the active soil layer (0-60 cm) of the non-irrigated soybean, and

20% in the 60-100 cm layer. Under irrigation conditions water consumption from the 20-40 cm layer is much more intensive than that of non-irrigated soybean, with 80% FC accounting for almost 28% and 90% FC for almost 33%. The difference is only 5%, but it cannot be considered insignificant since it equals 35 mm of water consumed. Conversely, in the 40-60 cm layer, ET is more intense at 80% FC, exceeding 6% (20 mm) at 90% FC. Under irrigation conditions, 91-92% of the total ET for 0-100 cm formed in the active soil layer of soybean (0-60 cm). All of the above is confirmed by the graphs in Figures 6, 7 and 8, which illustrates the formation of ET in soil layers in dynamics in the three variants of the experiment. Under non-irrigation conditions, the 0-20 cm layer provides the main amount of water throughout the growing period (Figure 6).

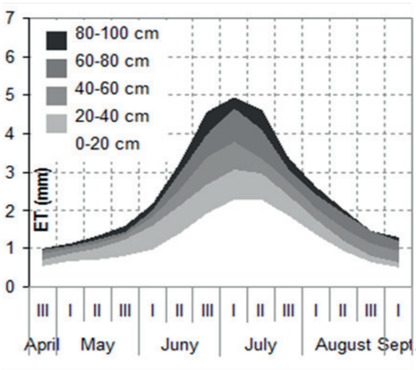

Figure 6. Layer formation of ET during the season, rain-fed condition

The involvement of 20-40 cm after mid-May is also visible, with the intensity of ET of this layer remaining until the end of flowering. The maximum ET of the underlying layers 40-60 and 60-80 cm below is during flowering and then gradually decreases and remains relatively constant during the seeding period. When maintaining soil moisture up to 80% FC, after the beginning of the irrigation period ET from the active soil layer increases rapidly, at the beginning of flowering water consumption is basically from 0-40 cm, but during the period of mass flowering and bean formation ET from 40- 60 cm reaches the upper two layers as values (Figure 7). As a result, during this part of the growing season (until July 20), water flow in the individual layers (within 0-60 cm) is close in value. The ET begins to decrease during the seeding period, but remains relatively high, as is the case for each of them. Consumption of water below 60 cm depth is insignificant.

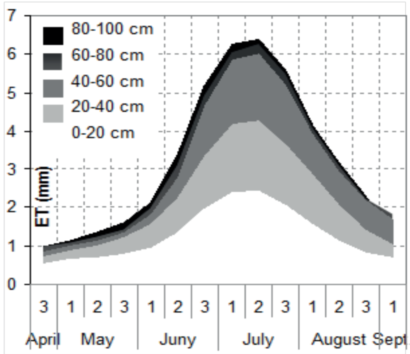

Figure 7. Layer formation of ET during the season, T2 treatment

When applying irrigation regime with high soil moisture up to 90% (T3), ET is formed from soil layer 20-40 cm more that 40-60 cm, the difference increasing substantially during the irrigation period and remains significant until the end of the growing season (Figure 8).

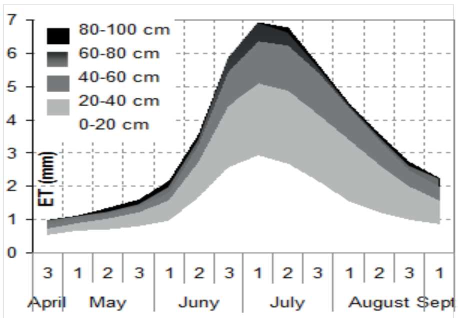

Figure 8. Layer formation of ET during the season, T3 treatment

The dynamics of water consumption from the 60-100 cm layer is similar to that of the previous variant.

Rainfall participation, irrigation rate and initial soil water content in the formation of evapotranspiration

Under rain-fed conditions, ET is formed due to the initial water supply and rainfall, and under irrigation conditions the irrigation rate is added.

According to Eneva & Valchanov (1986) rainfall compensates for an average of 73% of the ET of non-irrigated soybeans. When maintaining soil moisture more than 80% of FC, 43% of ET is provided by vegetation rainfall, 41% by irrigation rates, and 16% by soil moisture accumulated during the autumn-winter and early-spring periods. According to Dimitrova & Dimitrov. (1987), Chervenkova & Matev (2005), the irrigation rate participates with 40-60%, depending on the nature of the year. In the range of pre-irrigation soil moisture between 60 and 80% of FC, the relative participation of the components does not differ significantly, with the share of rainfall varying between 74-77% and the irrigation rate between 23 and 27% (Yust & Gorbacheva, 2017).

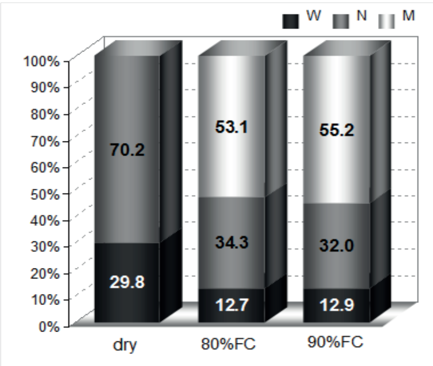

Figure 9. Relative participation of initial water content (W), rainfall (N) and irrigation rates (M)

Figure 9 shows the relative involvement of the three components in the formation of ET in the three variants of the experiment. Data refer to the 0-60 cm layer. Under non-irrigation conditions, rainfall provides an average of 70% of the ET, and the initial water supply falls to 30%. During the season of 2009 year, precipitation accounted for 63%, and the initial water supply - 37%, while the next year 2010, the relative share of the two components was 78 and 22%, respectively. The irrigation rate under irrigation is at the expense of the other two components. The differences between the two irrigated variants are minimal (about 2%) and have no practical significance. The irrigation rates provide more than 50% of ET, varying between 52 and 56% for T2 and T3, regardless of the nature of the year. Rainfall provides about 1/3 of the total ET, and the initial water supply occupies an average of 13%.

Water use productivity (WUP)

This indicator gives an idea of what yield is obtained for 1 m^3 of water consumed. It is calculated by dividing the yield (Table 3) by the total ET (Table 2). Figure 10 presents data by years and average experience. The average data show no significant difference between the two irrigation treatments.

Table 3. Yield in kg/da

Year	Treatment		
	T1 rain-fed	T2 80% FC	T3 90% FC
2009	103.7	192.2	196.7
2010	195.8	249.6	285.5
average	149.8	220.9	241.1

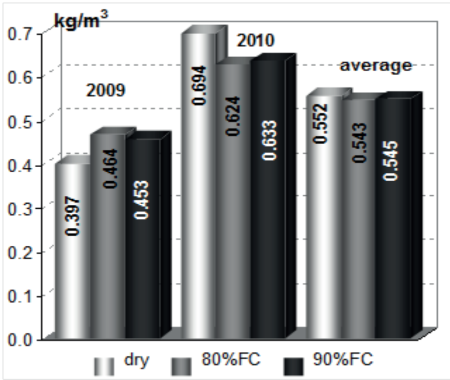

Figure 10. Effectiveness of ET depending of water supplying of soybean

CONCLUSIONS

A field experiment conducted with soybean, irrigated at two levels of soil moisture showed:

1. Evapotranspiration values depend on the irrigation regime applied and are affected by the maintained soil moisture level. Irrigation with soil moisture level of 80% FC increases water consumption by an average of 50% compairing with non irrigatied crop.
2. The dynamics of change of evapotranspiration as a function of the growing season is not significantly affected by the maintaining soil moisture level before irrigation.

3. The maximum daily values of evapotranspiration are reached during the grain filling period under both irrigation and non-irrigation conditions, but they differ in values. ET reaches a maximum of 6 mm and 6.3 mm in the second decade of July for treatments T2 and T3, respectively.

4. Irrigation rates have a major share in the formation of ET - up to 50% of the total amount of water available to the plants.

5. The major amount of water used by soybeans is located in the 0-0.6 m soil layer, especially during the most active growing season. Over 40% of the total ET is from the layer 0-0.20 m

6. The average productivity of the water used by the plants during the experiment period does not differ substantially, both under rain-fed and irrigation conditions - 0.55 kg/da for rain-fed treatment and 0.54 kg/da for irrigated soybean.

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