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EVAPOTRANSPIRATION OF COMMON BEANS (*Phaseolus vulgaris*) DEPENDING ON THE IRRIGATION REGIME

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ABSTRACT

The experiment was carried out in Agricultural University - Plovdiv in the period 2014-2016 to study the evapotranspiration of common beans crop under different irrigation levels. The used variety was *Dobrudzhanski 7*. The experiment was set up by the block method in four repetitions. Data from the following variants are used: 1) without irrigation; 2) 25% of the optimum irrigation rate (25%m); 3) 50%m; 4) 75%m; 5) with full irrigation rate (100%m). An optimum irrigated bean spends 385 mm (total) water on average in the layer 0-60 cm. The reduction of irrigation rates decreases the total evapotranspiration from 7% to 23% on average. For the variants with maximum irrigation and irrigation with 25% reduction of irrigation rate, the maximum values of evapotranspiration are registered at the beginning of grain filling phase, reaching 5-6 mm/day. The high values of evapotranspiration (over 4 mm/day) were observed from the first to the third decade of July. The increase of water stress induced by reduction of irrigation rates is a reason for reaching evapotranspiration maximum values earlier with 1-2 decades. In the same time, it has a negative effect on evapotranspiration values. Evapotranspiration is formed between 85-96% in layer 0-60 cm of the whole one-meter soil layer. From 50 to 60% of evapotranspiration are consumed by the soil layer 0-20 cm, depending on the year conditions. The annual irrigation rate forms over ⅓ (37%) of evapotranspiration for the optimum irrigated beans, as with the reduction of the irrigation norms its contribution decreases in favor of the precipitation and the initial water supply.

Keywords: common beans, evapotranspiration, water deficit, water use.

INTRODUCTION

Evapotranspiration (ET) of every crop culture is a basic element of expense in the water balance of the active soil layer. It is also one of the main factors, which determines the parameters of the irrigation regime. ET is such an indicator that is dynamic in time that is why its analysis and awareness for every single crop culture could help for more précised irrigation, for an increase of irrigation effectiveness.

For the conditions of our country there have been conducted a number of research field experiments related to ET of beans in the regions of Russe and Pazardzhik. Vitkov and Petkov (1972), Vitkov and Gruev (1973), and Vitkov (1975) has presented data according to which ET of beans, grown at an optimum irrigation in the region of Russe, is 263-346 mm for the layer from 0 to 60 cm. During the first vegetation period, harvest - bud formation, with approximately 30-day continuation, the values of daily ET are from 1-2 to 3 mm. The maximum was observed during the period of bud formation, mass flowering, during which for a ten-day period the values could reach 5-6 mm for twenty four hours. During the next vegetation stage the ET intensity is gradually reduced and in the period of bean formation it is reduced to 2-4 mm. Research has been made for the cinnamon forest soils in the region of Pazardzhik. The authors, Delibaltov and Sarkizov (1974) have registered a seasonal ET values up to 380 mm at the same distribution of the average day values by stages. Beans is a relatively flexible crop regarding the environment conditions. It is proven by the exclusively wide areal of its cultivation. Reasearch in this direction has been made by a number of authors around the world. The most intensive research activities related to beans irrigation has been carried out on the territory of North America and South America. It is proven that in the region

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of Iguala, Guerrero (Mexico) for receiving of maximum yield in the winter ET values are required to be not less than 256 mm, and in the summer - 317 mm (Estrada et al., 2001). For irrigation conditions ET varies from 201 to 242 mm (Morales-Rosales et al., 2006). In comparison with the above mentioned values, with the increase of the average day air temperature the total ET of beans grows. In the region of Sao Paolo (Brazil) at maximum irrigation ET values are between 327-467 mm, and at interrupted irrigation, depending on the year period and characteristics, ET is between 291-321 mm (Bergamaschi et al., 1989; Vieira et al., 1989; Vasconcellos and André, 1998). ET values of beans, cultivated in the conditions of Rio Grande do Sul (south-eastern part of Brazil), vary in the same range. Data of eight-year results, collected by Matzenauer et al. (2002), show that at optimum irrigation ET values vary from 337 to 384 mm without taking into account the harvest period. According to Wakrim et al. (2005), in the conditions of half-reduced irrigation norms ET intensity is not influenced by the water stress vduring the first ten days. After that it starts to decrease, reaching values up to 50% from the optimum irrigation values.

The present research aims at examining evapotranspiration of beans (total and average day values, ET formation components, the importance of the separate soil layers) in the conditions of optimum irrigation, irrigation with reduced rates, and without irrigation.

MATERIAL AND METHODS

The present research was conducted with the use of data from a three-year field experiment related to the irrigation regime of beans. The experiment was carried out in the experimental field of the Agricultural University - Plovdiv from Bulgaria on alluvial-meadow soil in the period 2014-2016. The used variety was *Dobrudzhanski 7*. The experiment was set up by the block method in four repetitions. The evapotranspiration was examined at the following treatments: 1) without irrigation; 2) with 25% of the optimum irrigation rate (25%m); 3) with 50% of the irrigation rate (50%m); 4) with 75% of the irrigation rate (75%m); 5) with full irrigation rate (100%m) - optimum (full) irrigation (m - calculated optimum irrigation rate). The time for irrigation was defined based on the data for the dynamics of soil humidity at variant 5, when it reached 80% of FC (field capacity) in the layer from 0 to 40 cm. The irrigation rate size at this variant was estimated for moistening until reaching FC of the whole active soil layer (0-60 cm). For this aim, there was an estimation of the dynamics of the soil humidity every 5-7 days by the weight method (Atanasov, 1972). For variants 2, 3 and 4 irrigations are given simultaneously with those for variant 5, having the relevant corrections of the irrigation rates. ET was estimated separately by variants, through the consequent balance of the water supply in soil - every 20 cm at depth of 1 m maximum. For this aim the following formula was used (Kirkova, 2003; Zhivkov, 2013):

$$ET = W_{initial} – W_{final} + M_p + M_i \text{ (mm)}$$

where:

- ET is the evapotranspiration for the examined period (mm);
- $W_{initial}$ and W_{final}: the water supply, correspondingly in the beginning and the end of the period (mm);
- M_p: the sum of the used precipitations (mm);
- M_i: the used part of the irrigation rate (mm).

When estimating the water balance, there was no growth of the root system. It is due to the fact that the balance was conducted by layers – 0-20 cm, 0-40 cm, 0-60 cm, 0-80 cm, 0-100 cm. There was not a registration of capillary raising of the soil waters. They can be found deep enough, that is why they do not participate in plant water supply. The use of the precipitations was determined by the method of the consequent approximations (Crafty, 1964). On the base of the received results there were established the sum and the average day values of ET for each variant, as well as the relative share of ET forming components (initial water supply, precipitations during the vegetative period and irrigation rate) and ET distribution in the soil layers. Values of water consumpltion were defined by ten-day periods and by phases.

RESULTS AND DISCUSSION

Meteorological characteristics of the experimental years

Evapotranspiration depends on the meteorological conditions during the vegetation period. Precipitations lead to new quantities of water supply in the active soil layer, temperature decrease, as well as air moisture increase in the lowest atmosphere layer. The temperature and the air water pressure deficit have an influence on ET intensity. Data for these three indicators by years and average for the whole period are presented in Table 1.

The first experimental year was characterized as middle humid (with probability of 19.8%). Drought was in the third decade days of June and the first ten days of July, which coincided with the end of the growth period and the period of bud formation - the beginning of flowering. The precipitation quantity in the period of bean formation and grain filling were between 30-40 mm for a ten-day period. At a great extent, it secured the water supply of plants. Regarding the temperature sum, the year is average with probability of 46.5%. Regarding the air moisture deficit, the year was humid with 96.3% probability.

Table 1. Meteorological factors for V-VIII period in the region of Plovdiv

Factor		Average for 105 years	2014	2015	2016
ΣN	mm	221.5 mm	288.7	301.6	210.3
	P%		19.8	13.2	41.5
ΣT°	°C	2625°C	2631	2748	2775
	P%		46.5	19.2	14.1
ΣD	HPa	1200.1 Hpa	796.7	1009.2	1352.5
	P%		96.3	80.0	21.3

**ΣN - precipitations; ΣT° - temperature; ΣD - air water pressure deficit, P% - probability.*

The second experimental year (2015) was characterized as humid having 13.2% of probability. Nevertheless, the period from the third decade of June to the second ten days of August was dry. The precipitation sum during the whole period was barely 44 mm. Practically, it meant that the year in the reproduction period of beans was dry. There were significant precipitations in the third decade of August (136 mm), but they were not of practical importance for yield. Regarding the temperature sum, the year was from average warm to warm, having 19.2% probability. Regarding the air water pressure deficit, it was middle humid having, 80% probability.

For the period May-August, the third experimental year (2016) was average regarding the precipitation probability (41.5%) and warm regarding the air temperature probability (14.1%). During the year there was considerably equal distribution of precipitations by decades, although their quantity was extremely insufficient. During the reproduction period there were barely 70 mm of precipitations. The sum of air water pressure deficit was 1352.5 HPa, characterizing the year as middle dry, having 21.3% probability.

Seasonal cumulative evapotranspiration

In the first experimental year, for the variant with no irrigation, the impact of meteorological conditions on ET determined its high total value of 299 mm. With the improvement of water regime, ET gradually increased. In result of the watering cancelation, the negative effect of drought reached 399 mm, in other words it increased with over 33%. When an average water deficit was made up through reduction of the irrigation norm with 30%, it had a low effect on the total values of ET. The favourable precipitation conditions were of great importance, too. The difference compared to the optimum irrigated for beans was below 7%. The more considerable reduction in water supply was for variants 2 and 3 (25 and 50% m correspondingly), but in both cases the difference is below 20% (Table 2).

During the second experimental year (2015) the maximum total values of ET were registered again for variant 5 (415.8 mm), and the minimum values for the variant with no irrigation (289 mm). The difference of over 43% was due to the higher air temperature from the beginning of July to the end of the vegetation period, as well as to the continuing drought during this vegetation period. In these conditions, there were also considerable differences for variants 2, 3 and 4 in comparison with the variants of no irrigation and optimum irrigation (Table 2).

Table 2. Annual evapotranspiration for common bean depending on irrigation regime

Variant	Evapotranspiration					
	mm	% to 1	% to 5	mm	% to 1	% to 5
2014				**2015**		
1	299.1	100.0	75.0	289.4	100.0	69.6
2	322.0	107.7	80.7	319.2	110.3	76.8
3	322.4	111.1	83.3	351.7	121.5	84.6
4	372.4	124.5	93.4	395.9	136.8	95.2
5	398.9	133.4	100.0	415.8	143.7	100.0
2016				**Average for 2014-2016 period**		
1	244.7	100.0	72.0	277.7	100.0	72.2
2	260.2	106.3	76.6	300.5	108.2	78.1
3	292.4	119.5	86.1	322.2	116.0	83.7
4	307.2	125.5	90.4	358.5	129.1	93.2
5	339.7	138.8	100.0	384.8	138.6	100.0

During the third experimental year (2016) the total amount of vegetation precipitations was lowest. Rainfalls dominated during the first half and the end of vegetation, drought was observed over the whole July. Furthermore, this year was the coolest among all three experimental years. As a result, ET for the non-irrigated variant was lowest of 245 mm. The gradually increase of irrigation rate led to increase in values, which reached 340 mm for the optimum irrigated variant. According to the results of the three experimental years, it was proved that the irrigation regime and the year conditions have influence on the total values of ET for the crop cultures, including beans (Table 2).

Average for the three experimental years, at non irrigation conditions, the total ET was 278 mm. It represented 72% of ET, established for the variant 5 (385 mm). The regular watering with 25% reduction of the irrigation rate reduced the water consumption of beans with 7% on average. For the variant with 50% of irrigation rate the water consumption was reduced with over 16%. There were close values of ET between the variant with 25% irrigation rate and the variant with no irrigation (difference of 8 mm) (Table 2).

Average daily evapotranspiration

In relation to the irrigation optimization, the total ET is of great importance, as well as ET of the separate periods of the crop culture growth. In the first vegetation period (from germination to the beginning of bud formation) beans uses relatively small quantities of water. With the beginning of the reproduction period, which coincides with the second or third decade of June, there is more intensive water supply. Depending on the time for sawing, the values of average day air temperature and the irrigation regime, ET reaches its maximum in the period between the first and the second decade of July, more rarely in the third decade. In this period plants are in the phase of bean formation and beginning of grain filling. That is why intensive physiological and biochemical processes run in plants, which requires great quantities of easy accessible water. On the other hand, this period coincides with the hottest time of the year when the temperature and the air water pressure deficit have the highest values. In the period of grain filling the intensity of water consumption gradually decreases. At the end of the period and during the period of ripening, it gradually reaches values close to those of the vegetation beginning, despite of the meteorological factors.

Figures 1, 2 and 3 show the average day trend of ET by years for the soil layer 0-60 cm. A number of previous surveys with various crop cultures are evidence that the greater value of water deficit is, the earlier ET maximum is realized. The reasons for that are mainly physiological. They have relation to the water deficit accumulated over time and the followed shortening of the periods between phases. In the conditions of no irrigation and no precipitations, ET maximum could be reached in an earlier period of vegetation (until finishing the easy accessible water in soil).

After that ET remains low despite the fact that plants have greater need of water, combined with the meteorological factors. Furthermore, there are considerable changes in its absolute values. For the conditions of the present research, for the variant of no irrigation, ET was formed with one or two decades earlier, and for the variant with maximum irrigation, ET was formed in the period of flowering. Values varied according to the year conditions, which could be seen clearly in the three graphics. Average for the three years, the maximum average day ET of non-irrigated plants was realized in the first decade of July, as it was 3.5 mm (Figure 4).

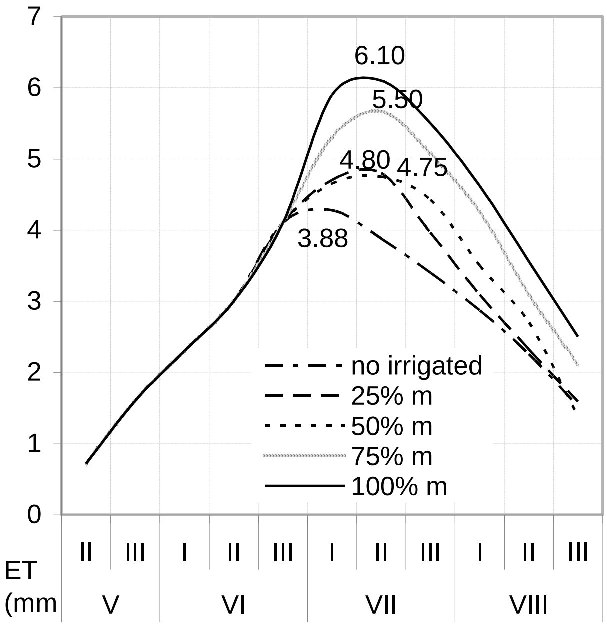


Figure 1. Trend of daily ET depending on irrigation rate during 2014

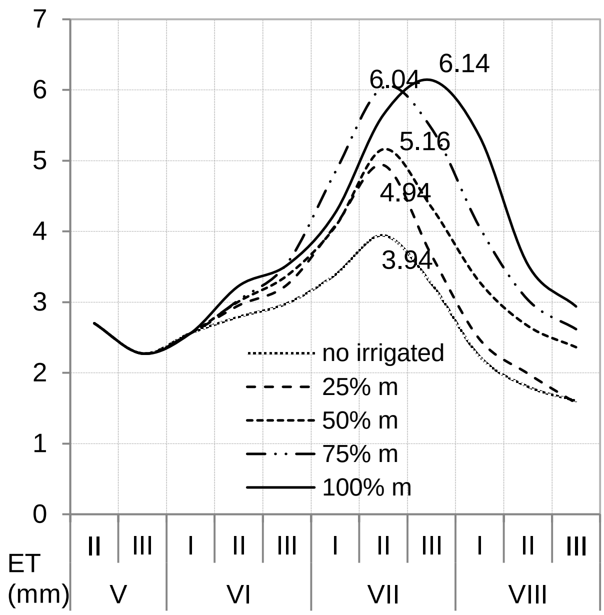


Figure 2. Trend of daily ET depending on irrigation rate during 2015

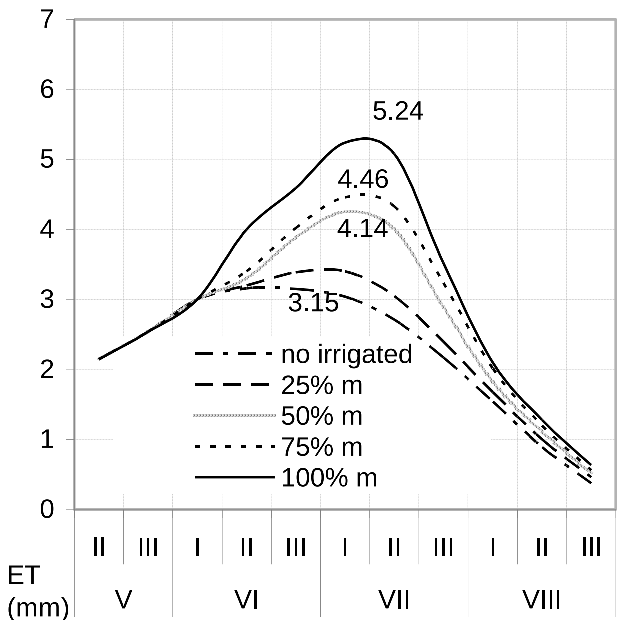


Figure 3. Trend of daily ET depending on irrigation rate during 2016

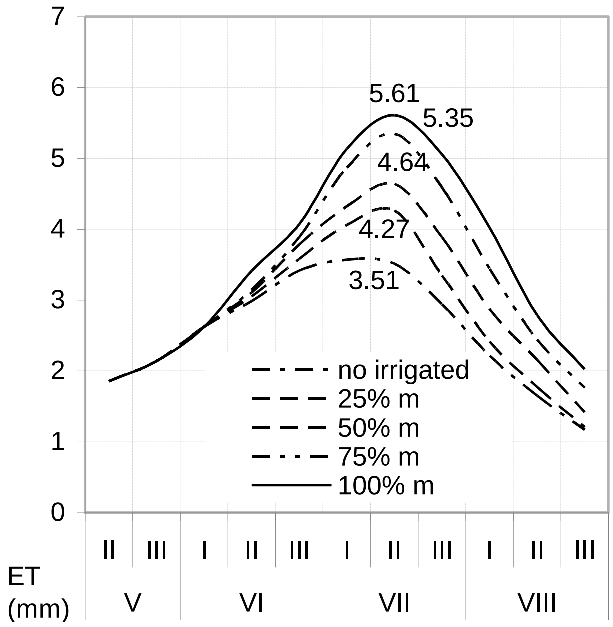


Figure 4. Trend of daily ET depending on irrigation rate average for 2014-2016

As it is presented in the graphics, until of the first irrigation, the average day course of ET for all variants is approximately the same. There are more considerable changes after the beginning of the irrigation period, when the used precipitations and the different irrigation rate are important for ET formation. Graphics clearly show the time of maximum water consumption, as well as the differences of ET average day course depending on the realized water regime. For the variants of full irrigation and 25% reduction of irrigation rate ET course is similar because of the increased use of precipitations from the reduced irrigation norms. This condition is not observed in the third experimental year because rainfalls are not enough to compensate the differences of the irrigation norms. Average for the three experimental years the maximum day values of water use for the full irrigated beans are 5.6 mm, and for the 75%m irrigated beans - 5.4 mm. Both maximum values are registered in the beginning of grain filling. The increase of water deficit through lower watering norms with 50% and more does not have considerable influence on the time for maximum reaching, but leads to a decrease of its values. In the more favourable years (2014 and 2015) they are about 5 mm/day, while in 2016 they barely reach 4 mm (4.6 mm on average). The difference in maximum values between the non-irrigated beans and that irrigated with 75% reduction of norms does not exceed 1 mm/day.

Results by decades presented in the four graphics could be used for evaluating the biological coefficients, as well as for a short-term prognosis of bean irrigation.

Formation of evapotranspiration of beans

- *Formation of ET by soil layers*

It is well known that the thickness of the active soil layer is an element form the formula used for estimating the size of the irrigation rate. Knowledge for the rooting system location and the water consumption by soil layers is of great importance for the correct calculation of the rate size. Thus, a maximum effect from irrigation can be reached - by irrigating a soil layer not thicker than it is necessary.

Table 3 presents data for evapotranspiration distribution for beans (in absolute and relative values), at depth up to 1 m, in different irrigation regime (treatments 1, 2, 3, 4 and 5).

Table 3. Formation of ET by soil layers depending on irrigation rate

ET / №	Soil layer (cm)													
	0 - 20		20 - 40		40 - 60		60 - 80		80 - 100		0 - 60		0 - 100	
	mm	%	mm	%	mm	%	mm	%	mm	%	mm	%	mm	%
2014														
1	197.3	58.1	69.2	20.4	32.6	9.6	24.6	7.2	16.1	4.7	299.1	88.0	339.8	100.0
2	203.8	60.9	90.4	27.0	27.8	8.3	7.6	2.3	5.2	1.6	322.0	96.2	334.8	
3	224.2	59.8	73.2	19.5	34.9	9.3	22.3	5.9	20.5	5.5	332.3	88.6	375.1	
4	226.1	57.4	114.9	29.2	31.4	8.0	11.6	2.9	9.6	2.4	372.4	94.6	393.6	
5	202.2	49.0	146.1	35.4	50.6	12.3	9.2	2.2	4.9	1.2	398.9	96.6	413.0	
2015														
1	174.0	55.4	73.5	23.4	46.1	14.7	9.5	3.0	10.8	3.4	293.6	93.5	313.9	100.0
2	186.9	51.6	80.6	22.2	54.5	15.0	25.6	7.1	14.9	4.1	322.0	88.8	362.5	
3	236.7	58.4	87.1	21.5	42.7	10.5	23.2	5.7	15.7	3.9	366.5	90.4	405.4	
4	272.1	57.9	72.7	15.5	84.7	18.0	23.6	5.0	16.7	3.5	429.5	91.4	469.8	
5	252.4	47.6	156.3	29.5	43.7	8.2	23.9	4.5	53.4	10.1	452.4	85.4	529.7	
2016														
1	143.4	49.3	56.0	19.2	34.6	11.9	28.3	9.7	28.8	9.9	234.0	80.4	291.1	100.0
2	180.8	59.6	46.1	15.2	28.1	9.3	24.8	8.2	23.4	7.7	255.0	84.1	303.2	
3	192.4	56.9	63.4	18.8	32.8	9.7	24.2	7.2	25.1	7.4	288.6	85.4	337.9	
4	199.6	62.0	83.2	25.8	17.1	5.3	12.6	3.9	9.4	2.9	299.9	93.2	321.9	
5	189.8	50.8	108.0	28.9	47.6	12.7	13.5	3.6	14.5	3.9	345.4	92.5	373.4	

In spite of the cultivation conditions, the most intensive water consumption is this in the surface soil layer 0-20 cm. On the one hand, it is due to the fact that the layer is most affected by the environment - it is heated most intensively by the sun. On the other hand, the layer accumulates even the smallest quantities of rainfalls. Furthermore, the surface layer is rich of nutrients, where the main part of the rooting system is located. In the conditions of no irrigation, between 49 and 58% of the total ET is formed in it. In the conditions of irrigation, the surface layer is more active in relation to the absolute and the relative values. For variants 3, 4, and 5, where the irrigation rate reaches the lower soil layers, there is almost the same water consumption in layer 0-20 cm. Differences in the relative share of ET in this soil layer for these variants are due to the increasing absolute total values of ET for the one-meter layer with the increase of irrigation rate size. Differences during the whole period of vegetation do not exceed 10%. For all irrigation options, the relative share of the soil layer 0-20 cm in the total ET of beans is between 50-60% (Table 3).

The layer 20-40 cm is weakly affected by environment that is why its water is spent mainly by the plant rooting system. In the conditions of no irrigation, between 19 and 23% of ET is formed in this layer for the whole one-meter soil layer. Differences between the separate variants are more considerable. The water supplied by irrigation norm of 25% does not reach this layer. Here, ET can be compared with ET of the non-irrigated option. It is formed only by the precipitations and the water stored before vegetation. High values of ET can be observed when in short time irrigation is followed by considerable rainfalls. Such results are registered for 2014. Increase in values is observed for the variant with 50% of irrigation norm because a great quantity of irrigated water reaches this layer. We must take into account that the increase of water deficit in time leads to smaller depth of soil humidity, and to gradually reduction of ET. Although,19-22% of the total ET is formed in layer 20-40 cm for the variant with 50% rate. The absolute values of ET in this layer can be found from 63 to 87 mm. For the variant with 25% reduced norms, these norms are sufficient to moist the soil in depth up to 40 cm, as part of the irrigated water reaches deeper layers. It leads to an increased share of this layer in comparison to the one-meter layer. Average for the three years it is approximately ¼ or 23.5%. Optimization of soil humidity for variant 5 leads to high water consumption in this layer, as it is ⅓ from the total (29-35%).

Absolute values (mm) *Relative values (%)*

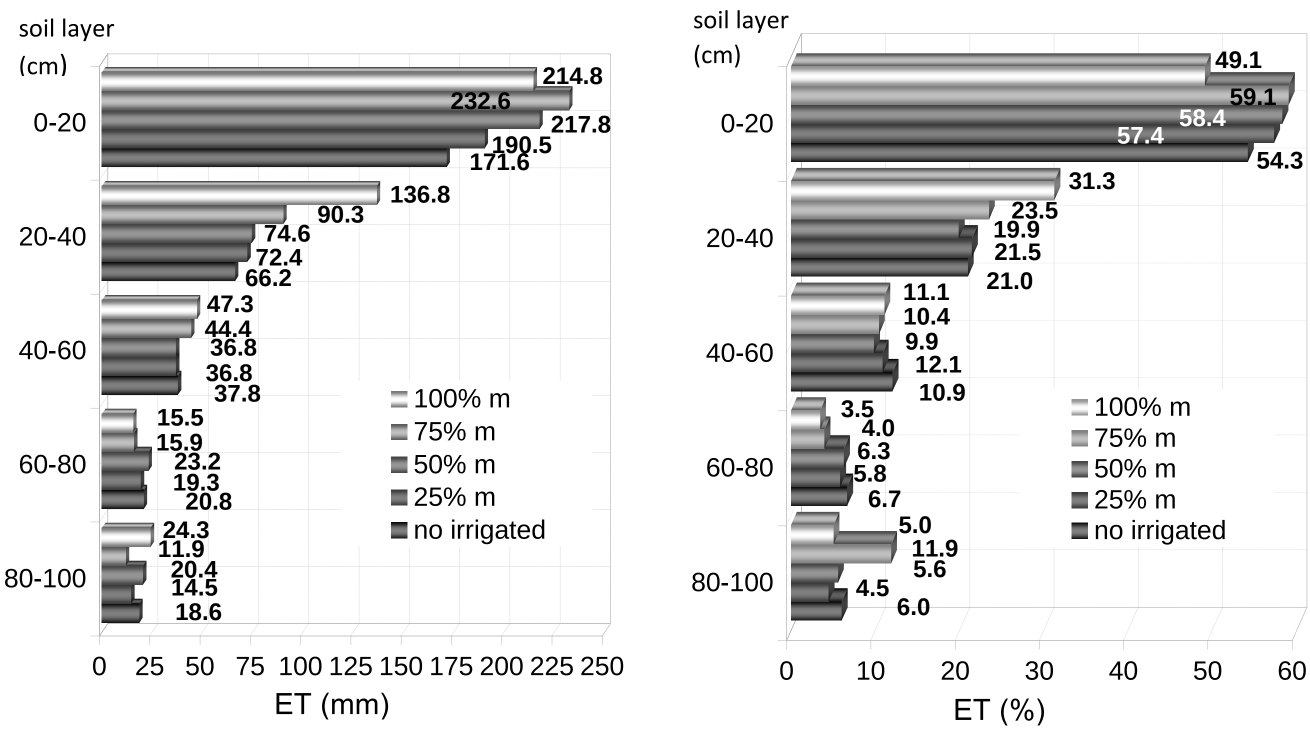


Figure 5. Formation of ET by soil layers depending on irrigation rate average for 2014-2016

For variant 4, a small part of irrigation rate reaches the layer 40-60 cm, and for the optimum irrigated bean, a considerable part of the rate reaches the layer. The rest is due to the precipitations. Thus, between 8-13% of the total ET is formed in this soil layer, which in absolute values (44-51 mm) is in the frames of one optimum irrigation norm. The table presents that bean plants use water from layer 0-60 cm, in spite of the fact that the water is easy or difficult of access. This is evident from the relative values of ET in this soil layer in comparison to the one-meter layer. Even in conditions of no irrigation, the spent total ET values in the active layer are between 80-90%. For the variant with irrigation norm 75-100% the relative share is between 95-97%. These results prove that the methodological approach is properly used for the research: time for irrigation is determined with reaching the relevant pre-irrigation humidity in layer 0-40 cm, and the watering norm is calculated to moist layer 0-60 cm.

Figure 5 shows the absolute and the relative participation of all soil layers in the formation of total ET at beans for the three experimental years on average.

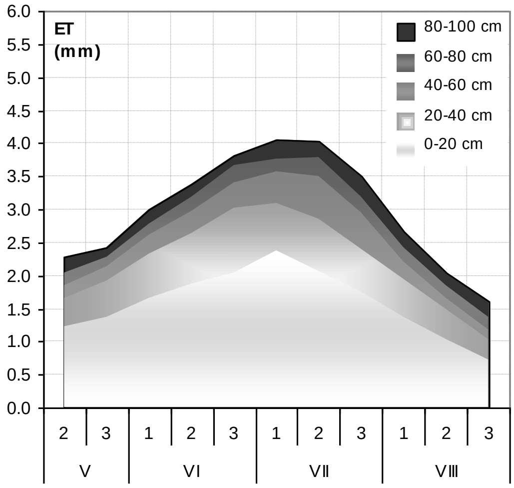


Figure 6. ET by layers in dynamics, variant without irrigation

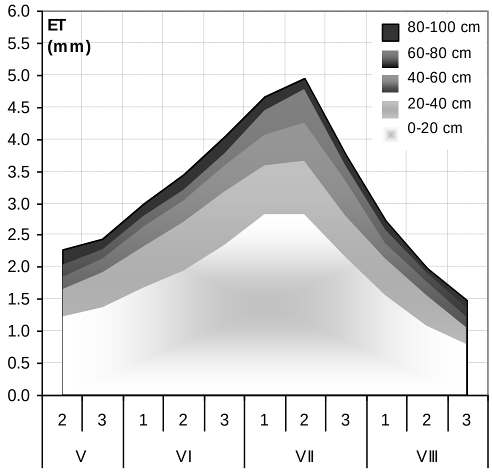


Figure 7. ET by layers in dynamics, variant 25% irrigation rate

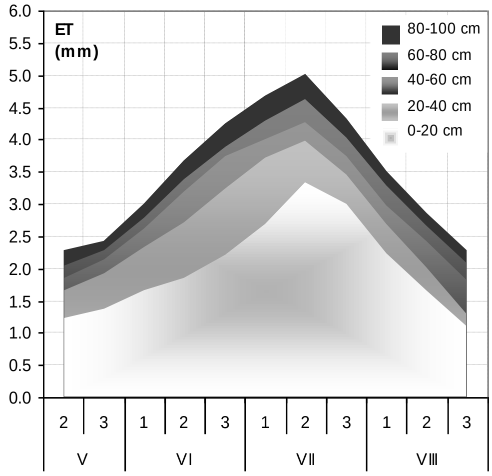


Figure 8. ET by layers in dynamics, variant 50% irrigation rate

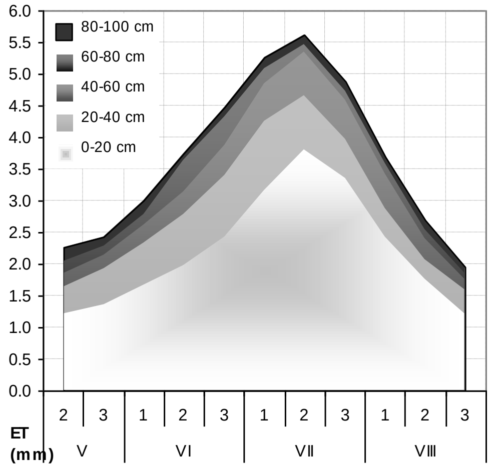


Figure 9. ET by layers in dynamics, variant 75% irrigation rate

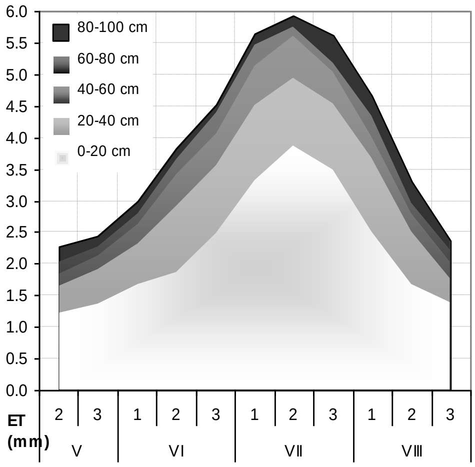


Figure 10. ET by layers in dynamics, variant 100% irrigation rate

Figures 6, 7, 8, 9 and 10 show (in dynamics and by decades) the water consumption by layers according to the irrigation regime. All figures present the whole one-meter layer, which is divided in intervals every 20 cm. For better comparison of results, all graphics are drawn in one and the same scale. Graphics show clearly the leading role of the surface layer (0-20 cm) for water supply of plants for all irrigation regimes during the whole vegetation period of beans. The great significance of layer 20-40 cm is proved, as well as of layer 0-60 cm. It means that the layer 0-60 cm coincides with the active soil layer of beans during the whole vegetation period.

- *Participation of precipitations, annual irrigation rate and initial water reserve in the formation of evapotranspiration*

Table 4 presents the absolute and relative values of precipitations (N), water reserve (W) and annual irrigation rate (M) in the formation of ET for layer 0-60 cm. In the conditions of no irrigation, precipitations have a basic role for ET formation because they are the only additional water source for plants. They supply a considerable share of water consumption for beans (from 61.7% of ET in the driest 2016 to 88.5 and 89.9% of ET in the rest two years). It is logical that in the first two years the water reserve forms 10-11% of ET, while in the dry 2016 - over 38%.

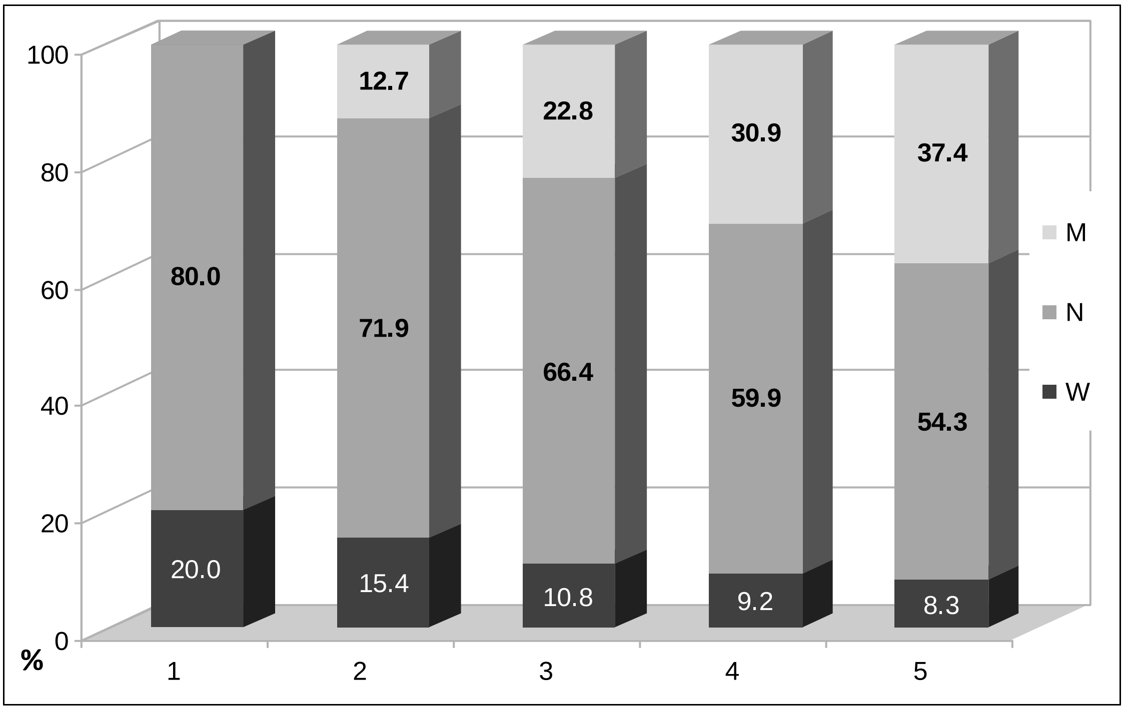
Table 4. Participation of precipitations, annual irrigation rate and initial water reserve in the formation of evapotranspiration

Treatments		2014				2015				2016			
		ET	W	N	M	ET	W	N	M	ET	W	N	M
1	mm	299.1	34.5	264.6	-	293.6	30.0	263.7	-	234.0	89.6	144.4	-
	%	100.0	11.5	88.5	0.0	100.0	10.2	89.8	0.0	100.0	38.3	61.7	0.0
2	mm	322.0	32.4	264.6	25.0	322.0	24.5	247.6	50.0	255.0	73.1	144.4	37.5
	%	100.0	10.1	82.2	7.8	100.0	7.6	76.9	15.5	100.0	28.7	56.6	14.7
3	mm	332.3	17.7	264.6	50.0	366.5	11.5	255.0	100.0	288.6	69.2	144.4	75.0
	%	100.0	5.3	79.6	15.0	100.0	3.1	69.6	27.3	100.0	24.0	50.0	26.0
4	mm	372.4	32.8	246.6	75.0	429.5	19.6	260.0	150.0	299.9	43.0	144.4	112.5
	%	100.0	8.8	71.1	20.1	100.0	4.6	60.5	34.9	100.0	14.3	48.1	37.5
5	mm	398.9	34.3	264.6	100.0	452.4	7.1	247.5	197.8	345.4	51.0	144.4	150.0
	%	100.0	8.6	66.3	25.1	100.0	1.6	54.7	43.7	100.0	14.8	41.8	43.4

In the conditions of irrigation, the participation of water reserve, precipitations and irrigation norm depends on the meteorological conditions during vegetation and the applied irrigation regime. In 2014, characterized as more humid year, for the maximum irrigated beans precipitations take more active part than irrigation norms (66.3 to 25.1%, correspondingly). The participation of the initial water reserve in ET formation for the options of full irrigation and no irrigation is practically equal (34.3 and 34.5 mm). Although, it’s relative share for the option of maximum irrigation coincides to 8.6% because of the increased absolute values of total ET. In the others two years, because of the great number of water supplies, the irrigation norm for the maximum option has a more considerable share in ET formation (43.7 and 43.1%, correspondingly), and in 2016 it is equal to the share of precipitations.

For the variants of reduced norms, the relative participation of irrigated water is reduced, and the participation of precipitations is increased, taking into account the reducing absolute values of total ET. There is a weak increase of the initial water reserve, but this is due to smaller absolute values of total ET for these conditions (Figure 5). For the variant with 75% irrigation rate, the relative distribution of the three components is due to the annual conditions, but the above mentioned trend is kept. Precipitations compensate 60% of ET on average, and the irrigation depth - 31%.

For the variants with small irrigation rates and considerable water deficit, the main part of water consumption is supplied by precipitations. The irrigation rate covers from 13 to 23% when realizing 25 and 50% of the maximum irrigation level.



*M - irrigation depth, N - precipitations, W - initial water supply.

Figure 11. Relative participation of precipitations, annual irrigation rate and initial water reserve in the formation of evapotranspiration, average for 2014-2016 period

Crop water use efficiency (CWUE)

The crop water use efficiency (CWUE) or productivity of ET is the yield of a unit of area realized by 1 mm water. Table 5 presents the data for this indicator at the separate options by years and average for the experimental period.

Table 5. Crop water use efficiency (CWUE) by variants and years

Variant	Yield (kg/da)	ET (mm)	CWUE (kg.da^{-1}.mm^{-1})	Yield (kg/da)	ET (mm)	CWUE (kg.da^{-1}.mm^{-1})
2014				**2015**		
1	153	299	0.51	147	289	0.51
2	199	322	0.62	193	319	0.60
3	212	322	0.66	231	352	0.66
4	232	372	0.62	241	396	0.61
5	239	399	0.60	252	416	0.61
2016				**Average for 2014-2016**		
1	126	245	0.51	142	278	0.51
2	173	260	0.66	188	300	0.63
3	228	292	0.78	224	322	0.69
4	255	307	0.83	243	358	0.68
5	267	340	0.79	253	385	0.66

For the research conditions, results related to this indicator prove that there is a connection between yield and water consumption of plants. During of more favorable years 2014 and 2015, the difference between the irrigation rates was small. During the third experimental year there is significant growth of ET productivity with the increase of irrigation rate. It is due to the stronger negative effect of water deficit on variants of lower irrigation. On the one hand, there is lower yield, and on the other hand, there is higher water consumption due to the meteorological factors.

CONCLUSIONS

For the conditions of the experiment the tested bean variety of optimum irrigation spends 385 mm water on average in the layer 0-60 cm. The reduction of irrigation rates with 25% decreases the total evapotranspiration with 7% on average. The variant supplied with 50% of irrigation rate has reduced evapotranspiration with 16% on average. The total evapotranspiration for variants irrigated with small rates (25%) is 77-81% from evapotranspiration for the variant with maximum irrigation.

For the variants with maximum irrigation and irrigation with 25% reduction of irrigation rate, the maximum daily values of ET are registered in the beginning of grain filling phase. According to the calendar, the high values of ET are available in the period from the first to the third decade of July. After that, the values gradually decrease. In conditions of no irrigation and low irrigation ET values reach below 2 mm for a day. The increase of water stress through reduction of irrigation rates is a reason for reaching maximum values of evapotranspiration earlier - with 1-2 decades. In the same time, it has a negative effect on evapotranspiration values.

Evapotranspiration is formed between 85-96% in soil layer 0-60 cm. From 50 to 60% of evapotranspiration are consumed by the surface soil layer (0-20 cm) depending on the year conditions.

The annual irrigation rate forms over ⅓ (37%) of evapotranspiration for the beans crop having optimum irrigation. With the reduction of watering norms, evapotranspiration reduces its use in favour of the precipitations and the initial water supply.

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