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INFLUENCE OF THE IRRIGATION METHOD ON THE SOYBEAN PRODUCTIVITY

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Abstract

The aim of this work is to determine the impact of irrigation methods on soybean productivity. The field experiment was conducted during the period 2008-2010 in Agricultural University, Plovdiv. Three irrigation techniques are tested – by gravity, microsprinklers and drip irrigation. A non-irrigation plot was the control. Irrigation for all three irrigation methods is given at 80% FC for the layer 0-0.60 m. Under non-irrigation conditions, the yield is between 104 and 202 kg/da. Irrigation by furrows increases yields with 66%. The average yield for this technique is 277 kg/da. Yield increases by over 75% and reaches 295 kg/da under sprinkler irrigation, the irrigation water use efficiency (IWUE) is 0.595 kg/m^3. Using drip irrigation, the yield increases by an average of 50% and reaches 250 kg/da, and the IWUE is much lower - 0.377 kg/m^3. From an economic point of view, the best results are by using sprinkler irrigation. It gives yield 18% higher than that of drip and 6% higher than that of furrow irrigation.

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

INTRODUCTION

Global climate change is adversely affecting the geographical area in which our country is located. To enhance the efficiency of Bulgarian agriculture, it is of particular importance to create conditions for the full utilization of the productive potential of natural resources - soil and water. In the context of the contemporary economic development of our country and the associated increasing consumption of fresh water, those technologies that require less water are becoming increasingly important. The efficiency of drip irrigation and micro sprinkling is determined by the amount of investment and annual operating costs, additional production, saving of irrigation water, etc. indicators. Such studies have been done for some crops, but soybean is not available.

In today's conditions, the choice of irrigation equipment is relatively large, due to the availability of a wide variety of elements of high quality materials on the market. The correct choice of irrigation method and type of irrigation equipment is an important prerequisite for efficient use of water, provision of suitable soil moisture and high yields from crops. According to research conducted in Austria, irrigation by sprinklers is more effective than irrigation by furrows, yield is 23% higher than that obtained under non-irrigation conditions (Klik A. & Cepuder P., 1991). In support of this are the results of a long experiment (20 years) exported by Paltineanu et al., 1994, according to which the yield and productivity of the total irrigation rate in sprinkler irrigation are higher than those in gravity irrigation. Riter & Searborough (1988) attach more importance to the irrigation regime than to the irrigation technique. Shuravilin et al. (2015) found that irrigation of early soybean varieties provided yields of 250-270 kg/da, but when drip irrigation was applied it increased and was 100 kg/da higher. According to the same study, maximum efficiency of sprinkler irrigation is reached at the seasonal rate of 400 mm, which is less than 70% of that found in drip irrigation. Babayan (2018) reports that carrying out 1-2 irrigations through the sprinklers during the critical phenophases leads to a significant increase in the yield of soybeans (from 44 to 101%), but according to the author the best results are obtained in combination between drip irrigation and mineral fertilization, with yields increasing by more than 20% comparing with sprinkler. Balakay et al. (2019) recommend that, in the case of sprinkler and drip irrigation, an soil moisture level 80% of FC for the 0-0.60 m layer. Significant water losses at soybean sprinkler irrigated have been reported by Zhelyazko & Vcherashnyi (2015). According to the authors the total coefficient of water loss during sprinkling is in the range 0.84-0.94, depending on the growing season.

The purpose of the research is to identify the impact of irrigation methods on soybean productivity and to find the most economically suitable of them.

MATERIALS AND METHODS

The experiment was conducted with soybean (variety Srebrina) in the period 2008-2010 on alluvial-meadow soil, in the experimental field of the Agricultural University, Plovdiv. Experience includes three variants with irrigation techniques - gravity (short closed furrows), micro sprinklers and drip irrigation. A non-irrigated variant was used for the control. Irrigations for all three variants were given at soil moisture 80% of field capacity (FC) for the layer 0-0.60 m. Irrigation time is determined by gravimetric method. The experiment is based on the method of the long plots in three repetitions, with the size of the experimental plots of 30 m^2 and the harvest plots - 10 m^2. The sowing was carried out mechanically in the last decade of April or early May, depending on the conditions of the year, at a density in the range of 25-30 plants per m^2. Soybean was grown after a corn maize precursor. All necessary agro-technical activities related to the cultivation of the crop have been carried out. Grain yield was determined at a humidity of 14%. By means of variance analysis (ANOVA1), the degree of proof of the differences between the variants, both in terms of yield and its main structural components, was established. On the basis of production data, output and costs associated with soybean production, an analysis was made to determine the economic performance of each of the irrigation techniques used.

RESULTS AND DISCUSSIONS

Water supplying by rainfall

The effect of irrigation and its intensity depend to a large extent on the amount and distribution of vegetation rainfall. As far as they are concerned, the experimental year 2008 is averaged with a 45% security and a vegetation rainfall of 231.0 mm. During the reproductive period this experimental year is dry, with the sum of rainfall below 25 mm from the third ten days of June to the second of September. At the end of vegetation rainfall 83 mm have no effect on irrigation and its effect on soybean productivity. The second experimental year is average dry, with a security of 69% and a precipitation amount of 190.2 mm. As a distribution, the vegetation rainfall in this experimental year is more favorable in terms of water supply of rain-fed soybean. The fall of about 60 mm in May and June, together with the autumn-winter moisture reserves are completely sufficient to secure the plants until the end of the growing season. During the reproductive period (July and August), precipitation is a total of 96 mm, with ¾ of them falling during the first half of the period, when soybeans bloom and form beans, there is a very intense water consummation, and the stress of meteorological factors is greatest. The third experimental year is close in characteristics to the first, with a sum of rainfall for the period May-September of 234 mm and a security of 52%. Typical for this experimental year is that most of the vegetation rainfall has fallen during the grain filling period (99.2 mm), when water demand begins to gradually decrease. Precipitation in June (44 mm) is of great importance for the beginning of the reproductive period.

Elements of irrigation regime

The difference in natural humidification conditions during the experimental years is reflected in the irrigation regime elements, with yearly data presented in Table 1.

During the first experimental year, the optimum soil moisture is maintained naturally throughout the growing season, extending to the period of mass flowering and the onset of beans formation, when the first 60 mm irrigation was applied in all three techniques. The second irrigation by gravity irrigation was also carried out during the period of mass flowering of bean formation with the norm of 50mm, while in the case of sprinkler and drip irrigation, the second irrigation was carried out 10 days later (during the period of bean formation and the beginning of grain filling). This difference in sprinkler is due to the slower depletion of water from the soil, which is why the irrigation rate is 50 mm. The delay of the second irrigation during drip irrigation is due to the daily and, at the same time, small rainfall, which hinder its realization. This creates a slight water deficit requiring a higher irrigation rate (75 mm). The third irrigation with all three techniques was performed during the period of grain filling, while maintaining the difference in the irrigation realization between the different variants of the experiment. Irrigation rates are consistent with the reported soil moisture. Under these conditions, the irrigation rate for sprinkler and gravity irrigation is practically the same (150 mm), while for drip irrigation it is 50 mm higher.

Table 1. Irrigation rates at three different techniques

№	period	Irrigation rates (mm)					
		Furrow		Sprinkler		Drip	
		m	M	m	M	m	M
2008							
1	II	50.1	148.7	60.0	151.1	60.0	201.4
2	II	50.1		50.0		74.8	
3	III	48.5		41.1		66.6	
2009							
1	II	55.1	232.6	55.1	236.8	55.1	216.2
2	II	56.7		56.7		44.4	
3	III	56.7		47.7		57.5	
4	III	64.1		77.3		59.2	
2010							
1	II	66.0	224.0	66.0	216.0	66.0	201.5
2	II	59.0		55.0		39.0	
3	III	50.0		45.0		49.0	
4	III	49.0		50.0		47.5	

m – irrigation rate, M – total irrigation rate
II – flowering and pod development, III – pod filling

The number of irrigations in the average dry year 2009 is the same for the three irrigation techniques. They are 4 and are distributed only within the reproductive period, since during this experimental year the vegetative period runs under conditions of optimal natural water supply. The first irrigation with all three techniques was carried out at the beginning of the mass flowering (July 20) with the standard 51mm. The second watering was carried out during the period of mass flowering and the beginning of bean formation. The third irrigation was carried out during the flowering and intensive beaning period, while in the drip and gravity irrigation, it was applied 5-6 days later when the grain irrigation period began. The last (fourth) watering is during the period of intensive grain filling (end of July and beginning of August). The total irrigation rate M in this experimental year was higher than in 2008, but varied within narrower limits (up to 20 mm) between techniques.

In the third experimental year, the number of irrigations was again 4, the first being at the beginning of flowering, the second during the period of mass flowering and bean-forming, and the third fourth - during the grain filling period. The irrigation rate for drip irrigation is the smallest, followed by that for sprinkler irrigation and gravity irrigation, with differences being relatively small. Compared to the previous two years, the circumstances allow the watering of the various techniques to take place at the same time.

Grain yield, depending on irrigation method

The impact of irrigation on soybean yield is presented in Table 2. During the first experimental year, irrigation under extreme drought results in a significant and statistically proven increase in yield, most notably in irrigation by furrows - 75%. During this experimental year, the differences in production and between techniques are also statistically proven. For example, in sprinkler irrigation, the yield represents 94% of that in gravity irrigation, but has been proven. A more significant difference is reported for drip irrigation, with a difference of nearly 13%. In both cases, the number of beans per plant can be considered as the main cause, since the data show deviations in the same range (6 and 14%, respectively). This is supported by data on the number and weight of seeds per plant. In the case of rain, the number of seeds decreases by 4% and their weight by more than 10%. In the case of drip irrigation, the number of seeds is reduced by almost 9% and the mass - by more than 11%. However, with all three techniques used, the yield is over 300 kg/da, which is close to the maximum productive capacity of this soybean (380 kg/da).

In the second year, which is characterized by medium dryness, the four irrigations increased yields by 2.2 times in furrow irrigation, 2.5 times in rainfall and 85% in drip irrigation, with statistically proven differences in each of the three cases (Table 2). During this experimental year, the yield results were the best in sprinkler, and probably one of the reasons is that the first three of the total 4 irrigations were realized at different stages of the flowering period, with the third coinciding with the intensive growth of the beans. In the case of gravity and drip irrigation, it is applied 5-6 days later (at the beginning of the seed filling period). Thus, as in the previous year, the structural elements of yield in gravity irrigation and in sprinkler vary within relatively narrow limits, but in drip the variations are more significant, which affects productivity. The number of beans per plant is about 8% less than that of sprinkler and about 10% less than that of gravity irrigation. In addition, during this experimental year, the mass of 1000 seeds for drip irrigation was 8% less than that for sprinkler and more than 10% compared to furrow irrigation. Under these conditions, the yield is below 200 kg/da (192.2 kg/da), behind the sprinkler by more than 25% and the furrow by more than 15%.

In the third experimental year, which is average and relatively favorable in meteorological conditions, soil moisture optimization increases yield by 27-28% in furrow and drip irrigation and by 48% in sprinkler. Relative to the non-irrigated soybean, these differences are statistically proven (Table 2). The yields of gravity and drip irrigation are almost the same, with a difference of less than 0.5%.

Table 2. Impact of irrigation method on grain yield in 2008, 2009 and 2010 years

Variant	2008				2009				2010			
	Y (kg/da)	differences ± kg/da	%	war-ranty	Y (kg/da)	differences ± kg/da	%	war-ranty	Y (kg/da	differences ± kg/da	%	war-ranty
Relative to rain-fed												
rain-fed	202.1	St.	100.0	St.	103.7	St.	100.0	St.	195.8	St.	100.0	St.
furrow	353.8	+ 151.7	175.1	C	228.6	+ 124.9	220.4	C	248.6	52.8	127.0	B
sprinkler	332.1	+ 130.0	164.3	C	261.7	+ 158.0	252.4	C	289.8	94.0	148.0	C
drip	308.8	+ 106.7	152.8	C	192.2	+ 88.5	185.3	C	249.6	53.8	127.5	B
Relative to gravity irrigation												
rain-fed	202.1	– 151.7	57.1	C	103.7	– 124.9	45.4	C	195.8	-52.8	78.8	B
furrow	353.8	St.	100,0	St.	228.6	St.	100.0	St.	248.6	St.	100.0	St.
sprinkler	332.1	– 21.7	93.9	A	261.7	+ 33.1	114.5	B	289.8	41.2	116.6	A
drip	308.8	– 45.0	87.3	C	192.2	– 36.4	84.1	B	249.6	1.0	100.4	n.s.
Relative to sprinkler irrigation												
rain-fed	202.1	– 130.0	60.9	C	103.7	– 158.0	39.6	C	195.8	-94.0	67.6	C
furrow	353.8	+ 21.7	106.5	A	228.6	– 33.1	87.4	B	248.6	-41.2	85.8	A
sprinkler	332.1	St.	100.0	St.	261.7	St.	100.0	St.	289.8	St.	100.0	St.
drip	308.8	– 23.3	93.0	A	192.2	– 69.5	73.4	C	249.6	-40.2	86.1	A
Relative to drip irrigation												
rain-fed	202.1	– 106.7	65.4	C	103.7	– 88.5	54.0	C	195.8	-53.8	78.4	B
furrow	353.8	+ 45.0	114.6	C	228.6	+ 36.4	118.9	B	248.6	-1.0	99.6	n.s.
sprinkler	332.1	+ 23.3	107.5	A	261.7	+ 69.5	136.2	C	289.8	40.2	116.1	A
drip	308.8	St.	100,0	St.	192.2	St.	100.0	St.	249.6	St.	100.0	St.
	GD (kg/da) 5% = 16.9; 1% = 24.3; 0.1% = 35.7				GD (kg/da) 5% = 21.7; 1% = 30.9; 0.1% = 44.7				GD (kg/da) 5% = 28.2; 1% = 42.8; 0.1% = 68.7			

Drip irrigation provides the highest number of beans per plant (average 58), while in the sprinkler they average 52 (difference is 11%). In gravity irrigation, the number of beans per plant is 39, ie. significantly less than with drip irrigation. In addition to the number of beans, drip irrigation accounts for the highest number of seeds per plant (average 120), although the differences between the three techniques are not statistically proven. Despite these advantages with drip irrigation, the sprinkler yield is 16% higher. The main reason is the higher yield by 4.4% by weight per 1000 seeds and by 17% higher yield per plant. The large number of beans in drip irrigation is largely offset by the small relative share of fully developed grains in them. Of the 148 seeds per plant planted, only 36.4% are fully developed, 44.7% are underdeveloped and 18.9% are missing. Compared to drip irrigation, in the case of rain and gravity irrigation, the seeds developed are more than 30% higher.

Figure 1 presents the average soybean yield data under non-irrigation (dry) conditions, as well as using the three irrigation techniques. Without irrigation, an average of 167 kg/da is obtained. Drip irrigation increases yield by 50% on average, furrow irrigation - by 66%. Sprinkling has the most favorable effect on yield, increasing it by an average of 76%. Compared to sprinkler irrigation, the yield for furrow irrigation is 94% and for the drip - 85%.

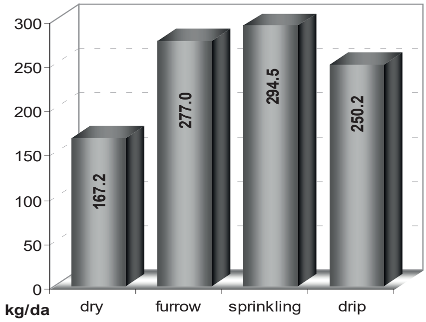

Figure 1. Soybean yield depending on irrigation method - average for three years

Irrigation water productivity (IWUE)

The productivity of the irrigation rate represents the additional yield of every 1 m^3 of irrigation water, but it can also be expressed as the amount of irrigation water to produce a unit of additional yield. The year data are presented in Table 3.

Table 3. The productivity of the irrigation rate

variant	ΔY (kg/da)	M (mm)	IWUE kg/m^3	IWUE m^3/kg
1	2	3	4	5
2008				
furrow	151.7	148.7	1.020	0.980
sprinkler	130.0	151.1	0.860	1.162
drip	106.7	201.4	0.530	1.888
2009				
furrow	124.9	232.6	0.537	1.862
sprinkler	158.0	236.8	0.667	1.499
drip	88.5	216.2	0.409	2.443
2010				
furrow	52.8	224.0	0.236	4.242
sprinkler	94.0	216.0	0.435	2.298
drip	53.8	201.5	0.267	3.745
average				
furrow	109.8	201.8	0.598	2.362
sprinkler	127.3	201.3	0.654	1.653
drip	83.0	206.4	0.402	2.692
ΔY - additional yield, M - total irrigation rate IWUE - irrigation rate productivity				

The use of irrigation water for drip irrigation is less effective. For the three experimental years the values are significantly lower than those for gravity irrigation and sprinkler (Table 3, column 4), with values ranging from 0.267 to 0.530 kg/m^3. Significantly higher efficiency of irrigation rate is reported for gravity irrigation, and in the first year of the experiment it is highest compared to the other two techniques, exceeding 1 kg/m^3.

Under the conditions of the experiment, the productivity of the irrigation rate of sprinkler irrigation varies within the narrowest range (between 0.435 and 0.860 kg/m^3). In addition, in the first year it is slightly lower than that of gravity irrigation, and in the second and third years it is the highest. Column 5 of Table 3 lists the values of the irrigation rate productivity giving an idea of the amount of irrigation water needed to obtain 1kg of additional yield. Here again, irrigation water is used most effectively at sprinkler, with an average of 1.653 m^3 of water (between 1.162 and 2.298 m^3) being consumed to obtain 1 kg of additional yield. The variation of these values in the gravity irrigation is the largest - between 0.980 and 4.242 m^3. However, on average during the experimental period, to obtain 1 kg of additional yield, most water is required for drip irrigation (2.692 m^3/kg). The average data of irrigation water productivity are illustrated in Figures 2 and 3.

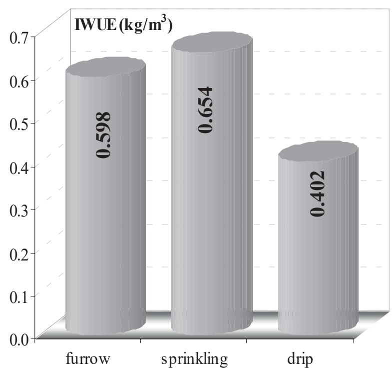

Figure 2. Irrigation rate productivity (kg/m^3)

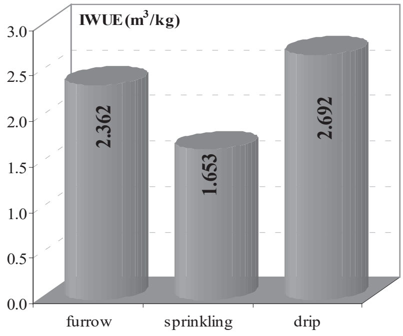

Figure 3. Nessesary irrigation water for producing 1 kg soybean (m^3/kg)

Economic Indicators

The parameters of the main economic indicators have been established and the costs have been determined on the basis of a technological map with specified prices for each agricultural practice (G. Georgiev et al., 2015). Four soil treatments are included, one being basic (autumn plowing), sowing costs, three herbicide treatments (soil, vegetative against wheat weeds and vegetative against deciduous weeds), as well as harvesting with a harvester combain and grain removal. Irrigation costs have also been added to the irrigation costs (excluding investment costs for the irrigation equipment). The soybean market price for 2019, which is 1 BGN/kg, is used to calculate revenue, meaning that the values of yield and total production are numerically the same.

- Costs of soybean producing

Under non-irrigation conditions, the costs are 76.14 BGN/da in the three experimental years. Irrigation increases costs, with gravity increasing by between 20 and 31% (average 27%) and reaching an average of 96.52 BGN/da (Figure 4), depending on the number of irrigations and the size of the irrigation rate vary between 91 and 100 BGN/da. In the sprinkler, costs vary in the same range, with an average of 96.47 BGN/da for the three years. The average costs at drip irrigation do not differ significantly (BGN 96.98/da), but unlike the other two techniques, there is practically no variation over the years (BGN 96.48-97.98/da). The data in the different variants of the experiment give reason to believe that the irrigation costs do not significantly depend on the method of irrigation.

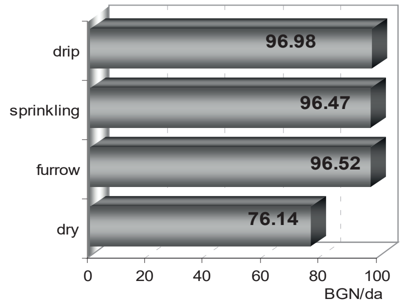

Figure 4. Producing cost in BGN/da

- Cost price

The cost of production under non-irrigation conditions does not differ significantly from that under irrigation, but is still higher (on average 0.46 BGN/kg), being relatively low (0.38-0.39 BGN/kg) in the average 2008 and 2010 years, but over years with prolonged periods of drought and lower yields, the cost of production has increased to over 0.70 BGN/kg, which is still below the market sale price of the production. The irrigation method does not significantly affect this indicator (Figure 5).

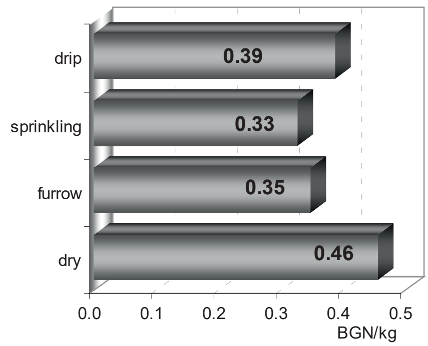

Figure 5. Cost price - average for three years

However, the lowest cost is recorded in the sprinkler, depending on the number of irrigations it varies between 0.28 and 0.38 BGN/kg (average 0.33 BGN/kg). In the case of gravity irrigation, the average increase is minimal (0.02 BGN/kg), but depending on the conditions of the year the variation is slightly wider - between 0.26 and 0.44 BGN/kg. The use of drip irrigation provides the highest cost of production, although it averages below 0.40 BGN/kg. However, in dry years, it may exceed 0.50 BGN/kg, while in more favorable years it ranges from 0.31-0.39 BGN/kg.

• Rate of profitability
This indicator represents the ratio between net income and production costs, with the highest average values being 205.3% for the conditions of sprinkler irrigation. Gravity irrigation (187%) and drip irrigation (158%) rank similarly to other economic indicators. Under rain-fed conditions, the rate of return is on average 120%.
• Net income
Under non-irrigation conditions, net income is relatively low, especially in dry years when yields are low and costs are commensurate with those in more favorable years. Therefore, in the average dry year 2009 it amounts to BGN 28/da, while for the other two, which are characterized as average, the profit is between 120 and 126 BGN/da. On average over the three years of non-irrigation experience, net income is 91 BGN/da (Figure 6).

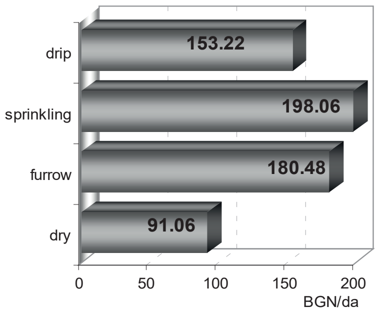

Figure 6. Net incom, in BGN/da

Irrigation increases net income significantly, especially in the drier years, although in such years its absolute values decrease due to higher irrigation costs. For furrow soybean irrigation, the average yearly profit increases from 25% to more than 2 times if there are periods of longer droughts during the year (as in 2008).
During average dry and dry years, furrow irrigation provides a net income increase of 4-5 times that under irrigation conditions. With this irrigation technique, the absolute values of this indicator range from 129 to 263 BGN/da, and on average over the three-year period it is 180 BGN/da. From an agronomic and profit standpoint, soybean sprinkling gives the best results, exceeding that in dry years by more than 20% gravity irrigation. However, in more climate-friendly years, the values for both techniques are commensurate. On average over the three experimental years, sprinkling provides a net income of 198 BGN/da, which is 9% higher than reported for gravity irrigation and 2.2 times compared to that under non-irrigation conditions (up to 5-6 times on average dry and dry years). The use of soybean drip irrigation increases the profit by 68% on average against non-irrigated soybean, depending on the cost of irrigation and the absolute yield obtained, ranging from 94 to 212 BGN/da (average 153 BGN/da), ie. an increase in the range of 28% to more than 3 times. However, net income from drip irrigation is inferior to that obtained under the other two techniques, regardless of the conditions of the year. It represents on average 85% of that in furrow irrigation and 77% (58 to 88%) of that in sprinkler.

CONCLUSIONS

The irrigation method does not significantly affect the elements of the irrigation regime in soybean, in the average years 3-4 irrigations are needed, and in the middle of the dry season - four times with rate of 50-60 mm. The average total irrigation rate for gravity irrigation, rain and drip irrigation is practically the same (201-206 mm).
Without irrigation, an average of 167 kg/da is obtained. Drip irrigation increases yield by 50% on average, gravity irrigation - by 66%. Sprinkling has the most favorable effect on yield, increasing it by an average of 76%. Compared to sprinkler irrigation, the yield for gravity irrigation is 94% and for the drip - 85%. Drip irrigation creates prerequisites for strong vegetative growth and the laying of more beans and seeds per plant than rain and gravity irrigation. As a result, the relative share of undeveloped and not fully developed seeds in the total yield increases. The mass of 1000 seeds is also smaller. For the conditions of this experiment, this is the main reason for the significantly lower yields than the other two methods.
Irrigation water is used most effectively in the sprinkler, with an average of 1.653 m^3 being consumed to obtain 1 kg of additional yield, and most of the water required for drip irrigation (2.692 m^3/kg) to obtain 1 kg of additional yield. The irrigation rate of sprinkler

irrigation exceeds that of furrow irrigation by 9% and that of drip irrigation by 63%.

The best economic results are obtained by sprinkler irrigation with the lowest production cost of 0.33 BGN/kg and the highest net income - 198 BGN/da. Thus sprinkling is recommended as a method of soybean irrigation. If there are not suitable conditions for sprinkler irrigation, it is also recommended furrow irrigation. With this type of irrigation, the average net income is 180 BGN/da. Soybean drip irrigation is not recommended because of its significantly lower agronomic and economic results. This method of irrigation can only be used when sprinkler and gravity irrigation are not possible.

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