

AGRICULTURAL ACADEMY

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“KONSTANTIN MALKOV” – SADOVO**

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**OPTIMIZING AND FORECASTING THE
SOYBEAN IRRIGATION REGIME**

ABSTRACT

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INTRODUCTION

Soybean is a crop of significant economic importance, which is why it is designated as one of the strategic crops of the 21st century. In the world production balance, it occupies third place after wheat and rice. In support of this are the data from economic analyzes and forecasts, according to which the areas, production, and yields increase with each subsequent year. According to some authors, it is grown in 62 countries, and according to others, they are more than 70. Soybean is mainly used for feed and in the food industry. Currently, $\frac{2}{3}$ of the world's protein meal consumption is provided by it. It is known that it finds wide application in various industrial areas, the production of medicines, etc. A significant part of the specialized scientific literature pays attention to the high content of proteins (35-50%) and fats (17-27%), and on this occasion, Zolotnitsky notes the following: *"No plant in the world can produce in 100 days as much protein and oil as soybeans, no plant in the world can compete with it in the number of products produced."* It is also the cheapest source of quality plant protein. Unlike the proteins that are synthesized in other crops, those in soybeans contain the eight essential amino acids necessary for building protein in animals and humans. It also contains carbohydrates, fiber, phytoestrogens, steroids, vitamins, and minerals, and soybean oil is very valuable because it contains omega-3 fatty acids. The qualities of soy as a plant are indisputable, but for it to be an integral part of modern agriculture, the economic balance of its cultivation should be positive. It is a plant for the monsoon climate. This means that under other conditions and without irrigation, yield may be compromised, especially in years with prolonged droughts during the reproductive period. This makes the efficiency of growing the crop under non-irrigated conditions uncertain. This risk also exists for the conditions of our country, since according to the multi-year data on precipitation, it is unevenly distributed during the growing season, and long-lasting droughts are a frequent phenomenon. These conditions predetermine irrigation as an activity having a significant contribution to obtaining high and sustainable yields. The results of studies carried out in different regions of the country show that soybean consumes between 400 and 500 mm of water, with an average amount of vegetation precipitation of about 250 mm. They, together with the autumn-winter moisture reserves from 20 to 70% of the water consumption of the culture, and the rest must be provided by irrigation. All this clearly shows that, under the country's climatic conditions, soybean irrigation must be an obligatory part of agricultural technology. The problems related to the irrigation regime, evapotranspiration, and irrigation techniques in this crop have been the subject of many years of research, and it has been scientifically proven that the biologically optimal irrigation regime does not always guarantee the best economic results, against the background of the increasing price of irrigation water and limited water resources. Although there is some clarity on the problems related to the application of regulated water deficit in soybean, the relevance of studies in this direction is not exhausted, especially since this crop responds specifically to irrigation, depending on the region in which it is grown. Increasing knowledge related to soybean irrigation would improve the efficiency in using hydro-technical facilities and more economical utilization of available water resources. Finding scientifically based ways to increase the efficiency of soybean production, including the application of the most suitable irrigation regime, would help it to gradually regain its rightful place in the sowing rotations in our country, namely - to occupy areas close to those of 70 and the 1980s.

Main conclusions from the literature review

Conducting scientific research work on an agricultural crop is usually related to its importance to people, as well as what is the interest in it. At the same time, an assessment is made of the lack of specific information and the possibilities of obtaining it through conducting experiments. In the introduction of the dissertation, it is noted that soy is a strategic grain-legume crop, having an extremely wide range of applications. It occupies 57% of the areas of all oil crops. In connection with this, a reference is made to its distribution and production worldwide. According to official data, the areas are constantly growing, and together with this - world production. According to FAO stat, in 2018 soybeans were grown on 125000000ha.

Any scientific work related to the study of agronomic factors of a certain agricultural crop requires knowledge about its morphology and biological features. In addition, in experiments related to the study of the irrigation regime, a very important element is the phenology of the crop. By using appropriate literature sources, this scientific problem in the present work is clarified.

For the formulation and specification of the purpose and tasks of the dissertation work, a thorough review of the specialized Bulgarian and foreign scientific literature concerning the irrigation regime of soybeans was made. It was made based on the results of the scientific research work of a large number of scientists (individually and in a collective), which are united in over 320 titles of articles, dissertations, books, monographs, studies, etc. The data is obtained as a result of experiments carried out in a large number of countries in Europe, Asia, Australia, Africa, and America. This allows getting an idea of the reaction of soybeans grown under the conditions of different irrigation regimes, implemented under different soil-climatic conditions, and a wide variety of varieties.

Parameters of the irrigation regime and criteria for scheduling the irrigation

Information concerning the depth of the active soil layer of soybean is considerable in quantity, but there is no consensus among different authors on this problem. Regardless of the fact that its variation in different publications ranges from 30-40 to 100 and more cm, the main part of scientists unite around the opinion that it should not exceed a depth of 50-60cm during the reproductive period, and before that – 0-30 cm. The main and most widely used criterion for scheduling irrigation is the pre-irrigation soil moisture, as a percentage of the FC (field capacity), and it is recommended to be in the range between 70 and 80%FC. In most of the studies, irrigations are scheduled according to an indirect criterion. Most often it is the bio-climatic method, as well as evaporation from a free water surface. The remote method, which uses an infrared thermometer, appears to be very promising.

The influence of irrigation regime on soybean productivity.

There are significant differences in yield data under optimal irrigation, depending on the location of the experiment and the cultivars used, with the variation being generally between 200 and 500kg/da.

Regarding the regulated irrigation regime, research in soybeans covers all options, such as canceling irrigation, reducing irrigation rates, and increasing the interval between irrigations. The problem of the sensitivity of plants to drought during the different phenophases is relevant, and the reported information is contradictory. It is believed that soybean reacts most negatively to soil drought during the period of pod filling, followed by the period of mass flowering and pod formation, and finally - the beginning of flowering. These conclusions are based on publications, many of which are from one-year experiments. The literature reference gives reason to consider that the scientific information related to the application of the periodic water deficit has a local character, and the research work for the complete clarification of the problem cannot be considered completely finished. In the event of a shortage of irrigation water, some authors recommend irrigation with rates reduced by between 20 and 30%, and in some cases – up to 50% and the assessment of all researchers is based on the relevant economic indicators. Although irrigation with reduced rates is relatively rarely applied in practice, research in this direction is still relevant, as the data from them are the basis for studying the "Water-yield" relationship.

Soybean evapotranspiration

According to the literature sources, the seasonal ET values of the optimally irrigated soybean vary widely - in the range from 300 to 800 mm. The variation in the values of the daily ET is also significant, with the maximum absolute values according to the literature sources being in the range between 4 and 8 mm per day. Much of the research shows that the irrigation rate provides between 30 and 50% of the annual ET of soybeans. Researchers are convinced that IWUE is an important indicator of how rationally water is used in the soil. The values are of a local nature, therefore the assessment must be made for specific conditions. According to the available specialized literature, the distribution of ET in soybean by soil layers has not been studied. Such information would be valuable for more precisely determining the depth of soil wetting, as well as for the permissible compromises in the conditions of irrigation water shortage. It is assumed that the "ET-yield" relationship is linear and is most correctly expressed by the FAO equations.

Irrigation techniques

For soybean, parallel studies to determine the most appropriate irrigation technique are limited, and the results are not consistent. Since it is quite possible to use any type of irrigation technique with soybean, there is a good reason for their parallel study and reporting of up-to-date information on their influence on the growth, development, productivity, and evapotranspiration of the crop.

AIM AND TASKS OF THE STUDY

The aim of the study is, based on long-term field experiments, to conduct a complex study of the irrigation regime and evapotranspiration at different degrees of water availability of soybeans and to find an optimal ratio between quantity and quality of yield, with the maximum economic effect of irrigation, as a parallel with this, to establish and propose for practice the most suitable methods for predicting irrigation.

Tasks

Establishing the parameters of the irrigation regime for soybeans in different years and analyzing the influence of the different degrees of water availability of plants on growth, development, productivity, and its components. Based on this, to propose useful for science and practice relationships.

Establishing the parameters of the relationship "Irrigation rate-yield" by using equations of different types and determining the most appropriate one, based on an analysis of accuracy and complexity.

Complex study of soybean ET (annual and daily values, formation, and distribution by soil layers) under non-irrigated conditions, optimal irrigation, as well as under irrigation with reduced irrigation rates. Establishing useful relationships for science and practice.

Establishing the parameters of the "ET-Yield" relationship by using equations of different types and determining the most appropriate one based on accuracy and complexity analysis.

Analysis of the influence of irrigation technique on productivity and its components, and on soybean ET.

Establishing the influence of the irrigation regime on the quality of soybean yield (physical and biochemical parameters).

Economic efficiency of soybean cultivation under non-irrigated conditions, optimal irrigation, as well as the application of a regulated irrigation regime by canceling irrigation and reducing irrigation rates.

Economic efficiency in optimal irrigation of soybeans, by using different irrigation techniques.

Determination of the values of the biophysical coefficients of ET according to different methods. Analysis of the accuracy and usability of established coefficients for indirect prediction of soybean irrigation.

Study the possibilities of using an infrared thermometer for remote determination of the water status of soybean plants.

MATERIAL AND METHODS

The experimental work is carried out in the Department of *Melioration, Land Management and Agrophysics* at the Agricultural University – Plovdiv and included a total of 4 field experiments.

Description of experiments

Field experiment carried out in the period 2003-2009

The "**Biser**" variety was used for the period 2003-2007, and in 2008 and 2009 it was replaced by the "**Srebrina**" variety. The experiment is one-factor with the following variants:

1. Without irrigation (control)
2. Irrigation at 80%FC pre-irrigation soil moisture for the layer 0-60cm (optimal /also control/)
3. Without first irrigation (irrigation scheme 0+++)
4. Without second irrigation (irrigation scheme +0++)
5. Without third irrigation (irrigation scheme ++0+)
6. Without fourth irrigation (irrigation scheme +++0)
7. Only the first irrigation (irrigation scheme +000)
8. Only the second irrigation (irrigation scheme 0+00)
9. Only the third irrigation (irrigation scheme 00+0)
10. Only the fourth irrigation (irrigation scheme 000+)
11. Reduction of all irrigation rates by 30% (70%*m*)
12. Reduction of all irrigation rates by 50% (50%*m*)
13. Reduction of all irrigation rates by 70% (30%*m*)
14. Reduction of all irrigation rates by 50% and inter-row wetting.

The experiment is carried out according to the block method in 4 repetitions, with the size of the experimental plots 30 m², and the harvest plots – 10 m². The soil of the experimental field is an alluvial

meadow. Sowing was done with a pneumatic seeder in the last decade of April or the beginning of May (according to the meteorological conditions of the year). A seeding density of between 20 and 25p/m² with a row spacing of 70cm was observed. The time for irrigation application is determined based on the data on the dynamics of soil moisture in variant 2, determined by the weight method. The soil moisture is monitored over a period of 7-10 days. Irrigation in all variants was carried out by gravity through short closed furrows. Irrigation rates for variant 2 are calculated so as to moisten the layer 0-60cm up to FC. In other cases, the irrigation rates are in accordance with the requirements for each specific variant. During the growing season, all agro-technical and plant protection activities were observed, thus fulfilling the rule of the only difference within the experiment, namely – the irrigation regime.

II. Field experiment, conducted in the period 2004-2006 at the Agricultural University, as a joint research project with the Soybean Experimental Station

The experiment is similar to the previous one, and the difference is mainly expressed in the pre-irrigation soil moisture (75%FC) and the depth of the soil layer (0-80cm). The "Mira" variety was used. There are 12 variants of the experiment and they differ in terms of the step with which irrigation rates are reduced. It is 25%.

III. A field experiment conducted in the period 2009-2010 to study the influence of high soil moisture

This two-year field experiment was conducted under a scientific project funded by AU-Plovdiv. Its aim is to investigate the influence of higher pre-irrigation soil moisture on ET and soybean productivity. The reason for conducting this experiment is the increasingly widespread penetration of drip irrigation in this culture. The experiment is one-factor and includes the following variants:

1. Without irrigation
2. Irrigation at 80% FC pre-irrigation soil moisture for the 0-60cm layer
3. Irrigation at 90% FC pre-irrigation soil moisture for the 0-60cm layer

The experiment was carried out using the method of long plots in four repetitions with the size of the experimental plots 30m² and the harvest plots - 10m². The "Srebrina" variety was used. A drip installation, sized and constructed specifically for this experiment, was used for irrigation.

IV. A field experiment conducted in the period 2008-2010 to study soybean irrigation techniques

The experiment has a duration of three years. The three main ways of irrigation have been tested - gravity (in furrows), sprinkler, and drip irrigation. Variants:

1. Without irrigation
2. Furrow irrigation
3. Drip irrigation
4. Sprinkling irrigation

The experiment is carried out using the method of long plots, with the area of the experimental plots being 30m² and the harvest plots – being 10m². The "**Srebrina**" variety is used. Gravity irrigation was carried out through short closed furrows. The drip irrigation is realized through an installation (described in the previous experience) with built-in drippers located 30cm apart. It is equipped with all the necessary elements, enabling the quality implementation of watering (filters, pressure gauges, non-return valves, etc.). Sprinkler irrigation is carried out by means of a micro-sprinkler installation, which can provide uniform irrigation of smaller areas, such as the experimental plots. For all irrigation variants of the experiment, pre-irrigation soil moisture of 80% FC is maintained for the 0-60cm layer.

RESEARCHED INDICATORS

Irrigation: monitoring of soil moisture and calculation of irrigation rates

As mentioned above, soil moisture in all experiments was monitored by the weight-thermostat method at a depth of up to 1m at 10cm intervals. Irrigation rates are calculated according to the formula: $m=10H\alpha(\delta^{mib}-\delta^H)$, where: m is the irrigation rate (mm), H – is the depth of the soil layer that must be moistened (m), α – the volume density of the soil/average for the same soil layer/ (t/m³), δ^{FC} and δ^H – respectively the humidity at the FC and the available (momentary) humidity valid for the same soil layer (weight %).

Phonological observations and physiological indicators

Phonological observations are mainly based on the alphanumeric classification of W.R. Fehr & Ch.E.Caviness. The accumulation of dry biomass in the different parts of the plant is determined by the weight method over an interval of 10 days, using 10 plants of each variant. At the same time, the area of the leaves of these same plants was determined by scanning the leaves and processing the images using a computer program. FSP and net photosynthetic productivity were determined. In all variants of experiment, I, a study of the root system is made. Its distribution in soil layers was established, as soil monoliths with dimensions of 10x35x10cm were cut at a depth of up to 100cm.

Evapotranspiration (ET)

Evapotranspiration was calculated layer by layer by variants, by balancing the water supply in the soil, through 20cm at a depth of up to 1m. The formula used:

$$ET = W_{\text{start}} - W_{\text{end}} + M_N + M_{\text{irrigation}} \text{ (mm)}$$

where: ET is evapotranspiration for the reporting period (mm);

W_{start} and W_{end} – respectively water reserve at the beginning and at the end of the period (mm)

M_N – the amount of usable precipitation (mm)

$M_{\text{irrigation}}$ – the used part of the irrigation rate (mm)

The usability of precipitation is determined according to the method of G. Crafty. Based on the results obtained from these calculations, the annual and daily values of ET were established for all variants of all experiments, as well as the relative share of the components forming it, and its distribution by soil layers.

The biophysical coefficients of evapotranspiration have been established only under conditions of optimal water supply for plants.

- Kc – the ratio between the real ET of the culture and the reference evapotranspiration (ET_0): $Kc = ET_c / ET_0$
- Z – ratio between the real ET for a certain period of time and the sum of the average day-night air temperature for the same period: $Z = ET / \Sigma T^\circ$
- R – ratio between the real ET and the sum of air-water pressure deficit /HPa/. It is calculated according to the following formula: $R = ET / \Sigma D$
- K_w – the ratio between the real ET and the evaporation from a free water surface (E_0), established by a "class A" evaporator: $KI = ET / E_0$
- Analogous to evaporation, using the evaporation rate calculated according to Ivanov's formula, one more coefficient was added - Ke.

Infrared thermometer measurement

The IRT measurements were made in an interval of 1-3 days around 2 pm in the afternoon, and the air temperature (measured in the shade) was taken in parallel. The values of dT° ($^\circ\text{C}$) represent the difference between the leaf temperature ($T^\circ\text{C}$) and the ambient temperature ($T^\circ\text{a}$):

$$dT^\circ = (T^\circ\text{c} - T^\circ\text{a})$$

Structural elements of yield and their determination

The structural elements of yield (table 1) were determined by year for all variants and for each of the experiments. Measurements were made on ten plants typical of each experimental plot. The data for each of the components were processed statistically by ANOVA analysis of variance. The table presents the structural components of yield included in the study, including the way they were measured and the corresponding unit of measurement.

Table 1. Structural components of the yield

Yield component	measure	note
Plant height (stem length)	cm	–
First pod height	cm	–
Number of branches	–	–
Number of internodes	–	total
		on the stem
		average per 1 branch
		on branches (total)
Length of internode of central stem	cm	average

Number of pods per plant	–	total
		on the stem
		on branches
Number of pods per node	–	on the stem
		on branches
		average per plant
Number of seeds in one pod		average
Weight of 1000 seeds	g	physical qualities of the seeds
Hectoliter weight	(kg/m ³)	
Yield from one plant	g	

Actual yield

The results are valid at 13-14% seed moisture, by weighting the yield from each harvest plot, which is equated to kg/da. The degree of evidence of the differences between the different variants and compared to the two controls was determined by variance analysis. The ANOVA software was used.

Irrigation water use efficiency (IWUE)

It is established in two reciprocal ways, namely:

- 1) additional yield (kg/da) for every 1mm of the irrigation rate
- 2) amount of irrigation water needed to obtain 1kg/da additional yield

Water use efficiency (IWUE)

It is also established in two reciprocal ways, analogous to the irrigation rate:

- 1) yield (kg/da) for every 1mm of water used
- 2) amount of water that must be consumed by the plants to obtain 1kg/da additional yield

Relationship *Irrigation rate – yield*

- 1) Relation *Total yield - irrigation rate*

- Regression: $Y = ax^2 + bx + c$
- Quadratic equation $Y = Y_c + (1 - Y_c)(2x - x^2)$
- Power equation: $Y = 1 - (1 - Y_c)(1 - x)^n$

- 2) Relation *Additional yield - irrigation rate*

- Regression: $Y = ax^2 + bx$
- Power equation: $Y = 1 - (1 - x)^n$

Y_c is relative yield without irrigation, **X** is relative irrigation rate

Relationship *Evapotranspiration-Yield*

- 1) Relation *Yield – annual ET*

- FAO equation – linear relationship between yield and ET: $Y = 1 - K_c(1 - x)$
- Two-power equation: $Y = [1 - (1 - x)^n]^m$
- Power equation: $Y = 1 - a(1 - x)^n$

In the equations: **K_c** and **a** are yield coefficients, **x** – relative ET

- 2) Relationship *Yield - ET by phenophases*

In connection with establishing the parameters of this relationship, the soybean growing season is divided into the following four sub-periods (phases): **first phase** – vegetative (from germination to the beginning of budding), the **second phase** – flowering and pod formation, **third phase** – pod filling, **fourth phase** – ripening.

The experimental data is processed by the method of least squares through the computer program YIELD, using the following formulas:

- power: $Y = \Pi[1 - A(1 - x)^n]$
- two power: $Y = \Pi[1 - (1 - x)^n]^m$
- linear: $Y = \Pi[1 - A(1 - x)]$
- aggregate: $Y = 1 - \sum A(1 - x)$

In the equations: **P** is a product, $\sum$ is a sum, **A** is a sensitivity coefficient of the phenophase, **x** is a relative ET for the phenophase.

Chemical composition of the grain

The chemical composition of the grain is determined according to established methods and standards, using 0.5 kg of seeds of each variant in 2 repetitions. The following indicators were

established: crude fat (%), crude protein (%), crude fiber (%), and crude ash (%). Standard methods are used.

Economic indicators

The economic analysis is made on the basis of the data on the costs related to the production of the culture and the income from the realization of the production. The includes all variants of the experiment, taking into account the following costs: Average yield (kg/da); Average realized price BGN/kg; Total production (the market price of soybeans in 2022, which is BGN 1.5/kg, was used to calculate revenues); Production costs (BGN); Production cost (BGN/kg); Rate of return (%); Net income (BGN/day).

Soil characteristic

According to FAO, the soil in AU - Plovdiv, where the experiments are carried out, is carbonate alluvial-meadow slightly solontic. It is well-drained and there is no waterlogging. The level of underground water is lowered and is below 2.5m. Table 2 shows the values of the main water-physical characteristics layer by layer.

Table 4. Main water-physical characteristics of the soil at the Agricultural University – Plovdiv

H (cm)	α (t/m ³)	δ^{FC} %	W^{FC} (mm)	W at 80%FC (mm)	W at 75%FC (mm)	WH %	Total porosity (%)
1	2	3	4	5	6	7	8
0-20	1.24	31.4	77.9	62.3	58.4	19.5	52
0-40	1.33	30.9	164.4	131.5	123.3	15.6	46
0-60	1.37	30.0	246.6	197.3	185.0	15.0	45
0-80	1.39	29.4	326.9	261.5	245.2	–	–
0-100	1.41	28.9	407.5	326.0	305.6	–	44

Legend: H – soil layer; α – bulk density; δ – humidity; W – water supply; WH – wilting humidity;

AGROMETEOROLOGICAL CHARACTERISTICS OF THE EXPERIMENTAL YEARS

Characteristics of the experimental years in terms of precipitation

The characteristics of the Plovdiv region in terms of precipitation are based on a 120-item statistical series (from 1899 to 2019 inclusive) with their total values for the period May-September. Based on this statistical series, the theoretical probability expressed as a curve (fig.1), as well as the empirical probability of all its constituent units, including years of the experiment, was calculated. According to the graph, 2005 and 2007 are wet years with a total of 450.9 and 463.2mm of precipitation, respectively, and probability – 3 and 2%. Four of the experimental years can be characterized as a medium, in which the difference in the amount of precipitation is insignificant. These are 2004 (234mm), 2006 (228mm), 2008 (231mm), and 2010 (234mm), and their probability is 45, 48, 46, and 42%, respectively. Medium dry are 2003 (179.1mm – the driest of all experimental years) and 2009 (190.2mm) with a probability of 72 and 68%, respectively. Apart from the amount, the distribution of precipitation during the different periods of vegetation is of crucial importance for the elements of the irrigation regime and the effect of irrigation. In 2003, the drought starts at the beginning of June and continues until the third decade of the month. The subsequent rainfall (70mm) during the period R1-R4 is not sufficient to compensate for the ET of the crop. Evidence for this is the absolute difference between precipitation and evaporation, which is negative throughout the reproductive period. The experimental year 2004 was more favorable, with the drought occurring in the third decade of June at the beginning of flowering. By the beginning of phase R5, the rainfall is only 30mm, and for the period R5-R6, it is close to 80mm. The difference between precipitation and evaporation is negative throughout the growing season. The wet year 2005 was characterized by a relatively even distribution of precipitation. The drought lasted about 20 days during the R4-R5 period but was followed by substantial rainfall, significantly exceeding the amount of irrigation rate. No waterlogging occurred during any phenophase of the growing season. In the middle year of 2006, the precipitation during the growing season was 35mm, but it was enough to cover this part of the vegetation. During the R1-R2 period, they are close to 120mm, and in addition, they provide part of the phenophase bean formation. Precipitation for this period exceeds evaporation. Drought is significant during R3-R8, with total rainfall for R3-R6 being just 26mm. Despite being very wet, the experimental year 2007 was characterized by a very prolonged drought, lasting from the emergence of the branches until the beginning of R6, when the rainfall was

only 0.7mm. Specifically for soybeans, this experimental year can be considered extremely dry. In the average year of 2008, an uneven distribution of precipitation was again observed. During the entire critical period from R1 to R6 inclusive, their sum is only 25mm, the main part of which is during the development phase of the beans (20mm). With a total evaporation of 721mm, the rainfall deficit was 564mm and comparable to that of 2006 and greater than the average dry 2003. The experimental year 2009 had a more favorable distribution of precipitation, with the period until the beginning of R2 being relatively dry. At the time of bean formation, rainfall conditions are most favorable, with a total rainfall of 48mm. During R5-R6 the rainfall was 22mm spread over three consecutive days. The last experimental year 2010 was favorable during the vegetative period. Half of the days during flowering and pod formation R1-R4 have precipitation, but small in amount and a total of 25mm. Conditions are favorable during the pod-filling phase. At the beginning of the phenophase, 100mm of usable rainfall falls in 3 days, then another 24mm falls in the middle of the phenophase.

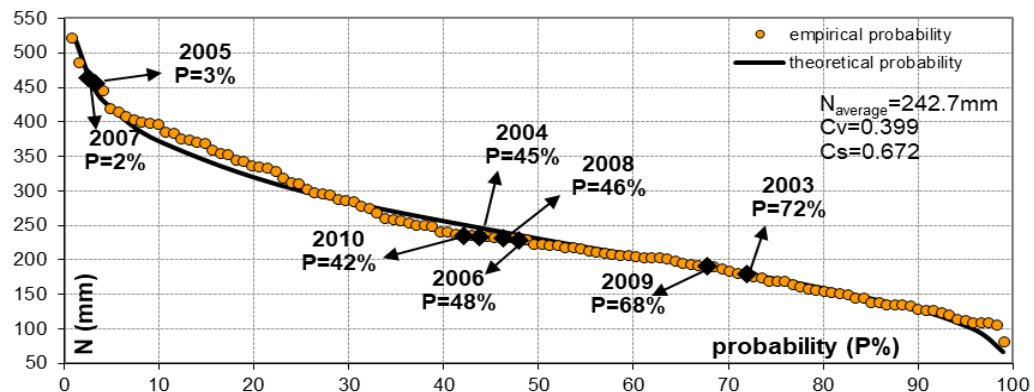


Fig.1. Precipitation probability for the period May-September in the Plovdiv region

Characteristics of the experimental years in terms of air temperature

The temperature conditions during the vegetation period have a determining importance for the intensity of water consumption from the soil, but in addition, they influence the phenological development of the crop, through the duration of the phenophases. Compared to precipitation, this indicator is much more stable in terms of variation. The analysis is based on a statistical series of 120 members, including the same years used in the precipitation characterization. The probability was calculated based on the total temperature values for the period of May–September, and the results are presented graphically in Fig.2. According to the data from the graph, 2003 and 2007 were warm years with temperature totals of 3363 and 3388°C respectively and a probability of 11 and 7%. The years 2009 and 2010 can also be attributed to this group, which have a temperature sum of 3326 and 3322°C, respectively, and a probability of 17 and 18%. Two of the experimental years were moderately warm. These are the years 2006 and 2008, which are respectively 34 and 32% probability and temperature sums – 3239 and 3243°C. The experimental year 2005 can be defined as middle in terms of temperature probability (P=41%) with a sum of 3210°C. The year 2004 can be defined as middle, to moderately cool, because with a sum of 3122°C, it has a probability of 62%. The experimental period did not include any cool years. Despite the differences between the years in terms of the temperature factor, they are all favorable for the optimal development of soybeans. It is known that the occurrence and passage of each phenophase in soybeans is tied to the recruitment of a certain temperature sum. To confirm this opinion, a relationship was established between the temperature sum and the duration of the phenophases in soybeans for the Plovdiv region. The data are presented in Table 3.

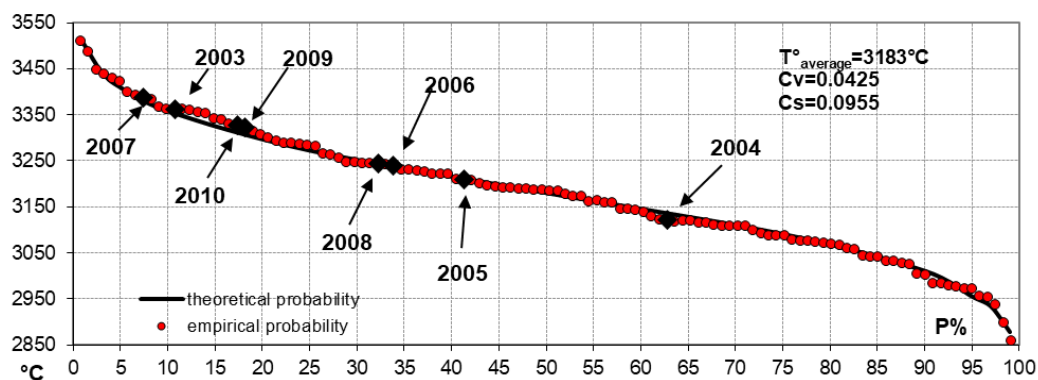


Fig.2. Probability of the temperature sum for the period May-September in the region of Plovdiv

Table 3. Parameters of the relationship between the temperature sum and the duration of the phenophases in soybean variety "Biser"

phenophase/period	to ΣT°		to $\Sigma T^{\circ}ef$	
	equation	R	equation	R
V1-V6 / vegetative period /	$D=0.051T^{\circ}-0.587$	0.904	$D=0.064T^{\circ}ef+13.97$	0.628
R1-R4 / flowering-pod formation /	$D=0.043T^{\circ}-0.343$	0.972	$D=0.069T^{\circ}ef+2.004$	0.917
R5-R6 / filling the pods /	$D=0.049T^{\circ}-6.019$	0.970	$D=0.087T^{\circ}ef-7.185$	0.884
R7-R8 / maturing /	$D=0.053T^{\circ}-2.265$	0.973	$D=0.099T^{\circ}ef-1.228$	0.878
R1-R8 / reproductive period /	$D=0.056T^{\circ}-26.32$	0.927	$D=0.080T^{\circ}ef+4.317$	0.652

The values of R from table 3 give the basis to determine the indicative limits for each phase of the vegetation, in terms of duration and required temperature sum. The data are presented in table 4 and are valid for the Biser variety and the soil and climatic conditions of Plovdiv.

Table 4. Phase duration and required temperature sum

фаза/период	необходима ΣT° (°C)	необходима $\Sigma T^{\circ}ef$ (°C)	продължителност (дни)
0-VE /sowing-emergence/	220 – 230	75 – 80	15
V1-V6 /vegetative period/	780 – 800	390 – 400	39
R1-R4 /flowering-pod formation/	840 – 860	480 – 500	36
R5-R6 /filling the pods/	700 – 720	410 – 430	29
R7-R8 /maturing/	470 – 490	240 – 250	23
R1-R8 /reproductive period/	2030 – 2050	1150 – 1170	88
V1-R8 /vegetation period/	2800 – 2850	1500 – 1600	127

Characterization of the years in terms of air-water-pressure deficit

The air-water-pressure deficit is an important meteorological indicator, as it has a significant impact on the intensity of evapotranspiration and on the rate of depletion of water from the soil, and from there the elements of the irrigation regime. The characteristic of the experienced years with regard to this indicator is made analogous to precipitation and temperature. For this purpose, a statistical series containing 97 articles was compiled. Data on the sum of the air-water-pressure deficit by year for the period May-September were used, based on which the theoretical and empirical probability of all years included in the series, including the experimental ones, was calculated. The driest year was 2007, with $\Sigma D=1794$ HPa and a probability of 10.2%. As middle years can be defined 2003 ($\Sigma D=1636$ HPa and $P=19.4\%$), 2004 ($\Sigma D=1675$ HPa and $P=18.4\%$), 2006 ($\Sigma D=1590$ HPa and $P=26.5\%$), 2008 ($\Sigma D=1582$ HPa and $P=28.6\%$) and 2009 ($\Sigma D=1629$ HPa and $P=21.4\%$), although there is a slightly more substantial difference in terms of the probability. This year is actually extremely dry during the reproductive period, which has a very significant effect on the elements of the irrigation regime. The year 2010 is characterized as the middle ($\Sigma D=1441$ HPa and $P=52.0\%$), and 2005 is wet ($\Sigma D=1137$ HPa and $P=91.8\%$).

Based on the detailed analysis of the meteorological situation during the soybean growing season, it can be considered that, despite the variation in the values of the considered indicators, they are within limits that do not in any way threaten the course of the growing season until its end. These differences can only limit or favor the processes taking place in the plant within the limits of the particular phenophase. In addition, the diversity of meteorological factors during individual vegetation

gives the opportunity to follow the reaction of the crop, depending on the specific conditions, and this contributes to the enrichment of knowledge related to the tolerance of the crop to the change in the climatic situation.

Data from the phenological observations during the experimental years

Table 5 presents the data showing the dates of occurrence of the phenophases by year. For the purposes of the present work, the determination was not made by variants, since the difference between them rarely exceeds two days, with slightly more significant discrepancies during the ripening period (up to 5 days), which, however, falls outside the irrigation period. Soybean can largely compensate for later sowing, and this is evident already at the beginning of the reproductive period, as the differences between the different years are smaller and smaller as it progresses. The vegetative period lasts between 42 and 64 days but is usually in the range between 50 and 60 days (average 54 days). The average duration of the period of flowering - pod formation is 36 days, the period of filling the pods – is 29 days, and here the variation by year is the weakest. The total length of the reproductive period averages 65 days, and the entire growing season is 142 days.

Table 5. Dates of occurrence of the main phenophases (variety "Biser") by year

code	Phenophase	2003	2004	2005	2006	2007	2008	2009	2010
–	sowing	12V	23IV	27IV	28IV	22IV	30IV	21IV	4V
VE	emergence	25V	4V	11V	10V	8V	16V	7V	15V
V1	1st leaf	31V	10V	17V	16V	19V	23V	13V	21V
V2	1st triple leaf	4VI	20V	26V	24V	1VI	29V	18V	27V
V3	Second triple leaf	7VI	24V	31V	30V	7VI	4VI	23V	4VI
V4	third triple leaf	13VI	30V	6VI	7VI	11VI	7VI	27V	8VI
V5	emergence of branches	18VI	9VI	15VI	15VI	18VI	16VI	5VI	15VI
V6									
R1	beginning of flowering	23VI	20VI	22VI	19VI	24VI	25VI	10VI	20VI
R2	mass flowering	29VI	25VI	28VI	1VII	29VI	30VI	15VI	25VI
R3	pod formation	13VII	7VII	7VII	10VII	7VII	8VII	2VII	7VII
R4									
R5	seed development	30VII	24VII	26VII	3VIII	20VII	29VII	22VII	23VII
R6		21VIII	29VIII	30VIII	31VIII	18VIII	26VIII	18VIII	21VIII
R7	maturing	22VIII	30VIII	31VIII	1IX	19VIII	27VIII	19VIII	22VIII
R8		23IX	18IX	27IX	26IX	14IX	15IX	3IX	4IX

RESULTS

Elements of the irrigation regime

In all the experimental years, irrigation in the variants was carried out in accordance with the parameters laid down in the methodical plan, as well as depending on the conditions of the year. As a result, the elements of the irrigation regime are specific to the conditions of the specific vegetation (table 6), and the data on the dynamics of soil moisture are presented graphically in graphs.

Irrigation regime by variants and years (experiment 1).

During the medium-dry and warm year 2003, a total of three irrigations were applied, the first of which was on July 10 during the period of mass flowering (R2). The second watering was applied on July 20 during the period of intense pod formation and the beginning of seed filling (R4 and R5). The third watering was applied on August 13, in phase R5 - seed filling. During this experimental year, variants 6 and 10 were not implemented, due to the lack of a fourth watering, i.e. they match variants 2 and 1 respectively.

Table 6. Irrigation rate by variants and years

variant			Biser					Srebrina	
			2003	2004	2005	2006	2007	2008	2009
2	100% _m	++++	171.1	120.9	65.0	150.0	218.6	148.7	232.6
3	100% _m	0+++	126.9	59.2	–	100.0	176.3	98.6	177.5
4	100% _m	+0++	118.7	61.7	65.0	100.0	131.0	98.6	175.9
5	100% _m	++0+	96.6	120.9	65.0	100.0	129.9	100.2	175.9
6	100% _m	+++0	171.1	120.9	65.0	150.0	218.6	148.7	168.5
7	100% _m	+000	44.2	61.7	65.0	50.0	42.3	50.1	55.1
8	100% _m	0+00	52.4	59.2	–	50.0	87.6	50.1	56.7

9	100% <i>m</i>	00+0	74.5	—	—	50.0	88.7	48.5	56.7
10	100% <i>m</i>	000+	—	—	—	—	—	—	64.1
11	70% <i>m</i>	++++	119.8	84.6	45.5	105.0	153.0	104.2	162.9
12	50% <i>m</i>	++++	85.6	60.5	32.5	75.0	109.4	74.5	116.5
13	30% <i>m</i>	++++	51.4	36.3	19.5	45.0	65.1	44.6	69.7
14	*50% <i>m</i>	++++	85.6	60.5	32.5	75.0	109.4	74.5	116.5

* inter-row irrigation; *m* – maximum irrigation rate

Under the conditions of 2004, in order to maintain pre-irrigation soil moisture of 80% FC for the layer 0-60cm, a total of two irrigations were carried out in the experiment with the Biser variety, the first being in the middle of July (15-17VII) in the bean formation phase. After about 20 days (4-5VIII), in the phase of filling the pods, the second irrigation was applied. The variants with reduced irrigation rates and the optimal variant (respectively 11, 12, 13, 14, and 2) received two irrigations each. One irrigation is applied to variants 3 and 4, which in this case are duplicated by 8 and 7, respectively. Variants 5 and 6 duplicate the optimal one, and 3 and 10 do not materialize because they coincide with the non-irrigated one. In the wet year 2005, one irrigation was carried out in the period 29-30VII. At this time the plants complete the period of flowering and pod formation and the phenophase of pod filling begins. Irrigation was given at a pre-irrigation soil moisture of 74% FC. Under these conditions, only the optimal variant and the variants with reduced rates were implemented.

In 2006, the middle year of precipitations, soybeans have irrigated a total of 3 times. The first irrigation was carried out on July 20 during the period of mass flowering - bean formation (R3-R4), with pre-irrigation humidity for the layer 0-60cm 81.3%FC. The irrigation rate for the optimal variant is 50.0mm. The second irrigation was carried out on August 2 during the beginning of the pod filling phenophase (R5), at a pre-irrigation humidity of 79.3% FC. The irrigation rate for the optimal variant is also 50.0mm. The third irrigation was carried out on August 18 during the period of pod filling (R6), with a pre-irrigation humidity of 80.7%FC. And with this watering, the norm for the optimal variant is 50.0mm. In this experimental year, variants 6 and 10 were not implemented, due to the lack of fourth irrigation. These are identical to variants 2 and 1 respectively.

In the extreme year of 2007, a total of three irrigations were carried out, the first of which was given in the mass flowering phenophase on June 29. The second irrigation was given on July 12 during the bean formation period, and the third - during the pod filling period (August 1). Because there is a more substantial variation in pre-irrigation moisture in this experimental year, the difference in the number of irrigation rates between the three irrigations is greater. Variants 6 and 10 were not realized, due to the lack of a fourth irrigation. These are identical to options 2 and 1 respectively. In 2008, the experiment was conducted with the Srebrina variety. A total of three irrigations were implemented. The first of these was carried out on 8 July during the period of mass flowering and just before the beginning of the pod formation phenophase, the effect of which was through R3. The second watering was applied in the pod formation phase (around the middle of the phase) on July 21. The third watering was carried out on August 4 in the phenophase pod filling. During this experimental year, all irrigations were given at a pre-irrigation humidity of about 80% FC, which is why the irrigation rates are approximately the same size. Again, variants 6 and 10 have not been implemented.

The year 2009 is specific in terms of abiotic factors. They create the conditions and the need to carry out 4 irrigations. The first was carried out on June 21 during the period of mass flowering (R2). The second irrigation was carried out on July 8 and was within the limits of the mass flowering and pod formation phenophase (R3-R4). The third irrigation was carried out on July 22 at the beginning of the pod filling phenophase (R5), and the fourth - 9 days later, in the same phenophase. In this experimental year, some differences were observed between the irrigation rates determined for each of the irrigations, but this was a result of the differences in the pre-irrigation moisture found in each of them.

In order to analyze the influence of a specific irrigation regime carried out in different years, in all variants of the experiment, the layer-by-layer (through 20 cm) change in soil moisture was dynamically determined. Fig. 3 and 4 show sample graphs (available in the dissertation) showing the change in soil moisture under non-irrigated conditions and under optimal irrigation.

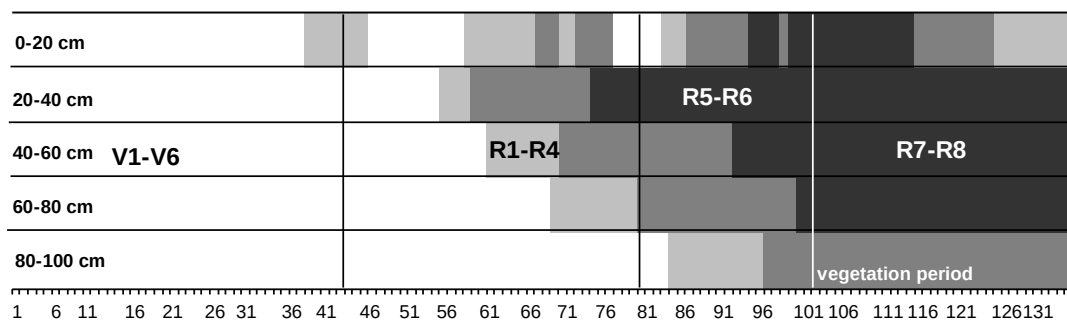


Fig.3. Dynamics of soil moisture under non-irrigated conditions in a mid-dry year

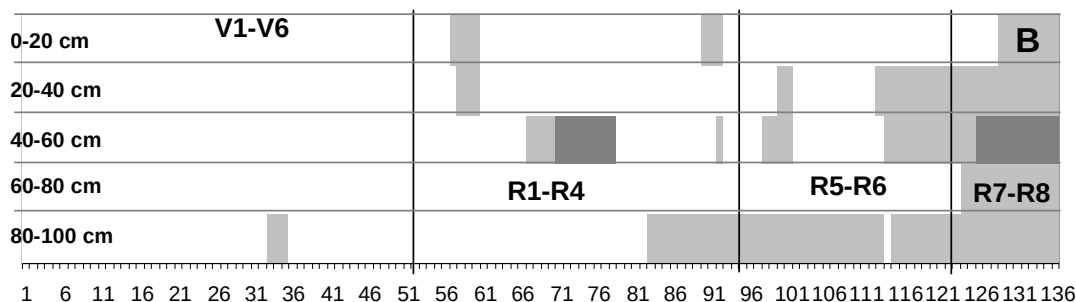


Fig.4. Dynamics of soil moisture in a mid-dry year and irrigation with a rate of 100%

Irrigation regime by variants and years (experiment 2).

Due to the slightly lower pre-irrigation humidity and the deeper calculated soil layer (pre-irrigation humidity 75% FC for the 0-80cm layer), the irrigation scheme for the Mira variety includes a maximum of three irrigations.

In 2004 and 2006, a total of 2 irrigations were carried out. The first is during the pod formation phenophase. The second watering is in the phase of pod filling. Under these conditions, variant 5 coincides with the optimal variant (variant 2), and variants 3 and 4 receive one watering each. Thus, they match variants 7 and 6 respectively. Variant 8 is not implemented because it duplicates the dry one. Variants 9, 10, 11, and 12 also receive 2 irrigations each, with the corresponding reduction in irrigation rates. The irrigation rate for the optimal variant is 156 and 177 mm, respectively, and for the others - according to the specifics of each of them.

In the wet year of 2005, one watering was carried out during the period 28VII - 30VII, in the phenophase of pod filling. Before watering (on 25VII), the soil humidity is 77%FC. Due to the fact that only one irrigation was applied, only the variants with different irrigation rates were implemented. The irrigation rate in the optimal variant is 75 mm.

In the course of the analysis of the dynamics of the water supply and soil moisture respectively, some general hypotheses were confirmed, as follows:

- In irrigation with reduced irrigation rates, each subsequent watering restores the soil's water supply to a lesser extent, thus causing a water deficit that grows over time. The greater the reduction in irrigation rates, the greater the step by which this deficit grows over time. The number of irrigations is also important. With the same reduction in the irrigation rate, the greater number of irrigations (vegetation with prolonged droughts) leads to a more significant decrease in the water reserve after the last irrigation (due to superimposition of the deficit in time) and vice versa (in shorter droughts and in more-small number of irrigations). The greater the reduction in irrigation rates, the more pronounced this result (fig. 5 and 6).

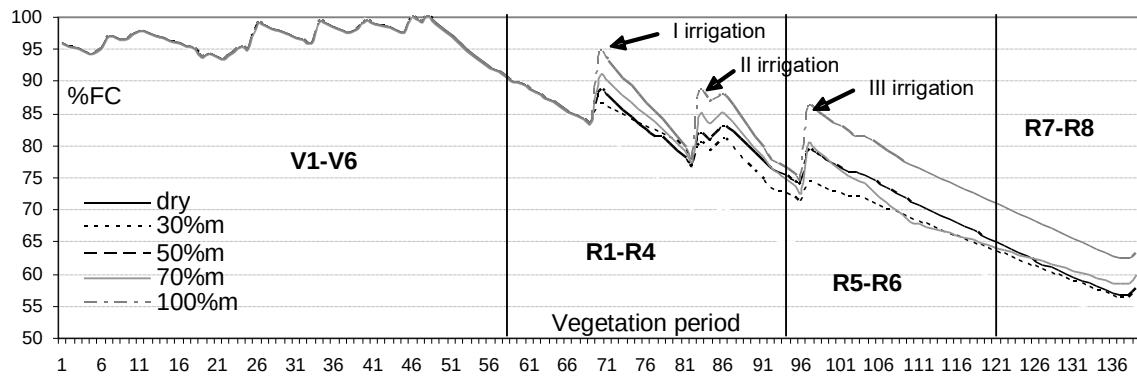


Fig. 5. Dynamics of soil moisture during irrigation with different irrigation rates and implemented 3 irrigations

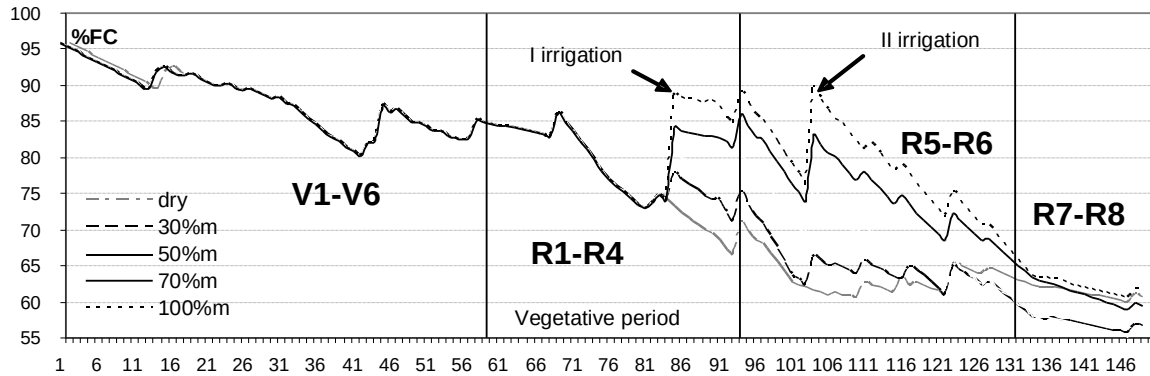


Fig. 6. Dynamics of soil moisture during irrigation with different irrigation rates and 2 irrigations implemented

- Variation of soil moisture decreases with increasing range (thickness of the soil layer) in which its variation is studied. The most significant is the variation in the surface soil layer (0-20cm), because it absorbs all or part of the precipitation, is moistened up to FC at all irrigation rates, is subject to the direct influence of abiotic factors, and in addition, contains itself a significant part of the root system. As the thickness of the layer increases, the indicated influences gradually decrease, and some of them (those of abiotic factors) even disappear. This leads to a gradual decrease in the variation of soil moisture. When including the data for the deepest layers (80-100 and somewhat 60-80cm), where irrigation water does not reach even with optimal irrigation, the variation is minimal.
- The irrigation regime influences the variation of the water supply and soil moisture. Fig. 7 shows the influence of the size of the irrigation rate on the variation of the water supply and, respectively, of the soil moisture. The drawn lines approximate the points having coordinates the values of C_v for the given soil layer (Y) and the relative irrigation rate (X). The data from all experimental years are included and cover the entire vegetation period (135-150 days, respectively values). The purpose, in this case, is to track whether, with an increase in irrigation rates, the C_v values decrease. The first graph (A) presents the data valid for soil layers of different thicknesses (from 0-20 to 0-100cm). In non-irrigated conditions and in the case of irrigation with small irrigation rates, the consumption of water from the surface soil layer is compensated by the precipitation and the supplied irrigations, which is why the variation of soil moisture is within narrower limits (in the general case). As the depth increases, the income of water often lags behind the expenditure and the soil dries out quickly. Therefore, the humidity during the growing season varies within much wider limits. As the irrigation rate increases above 50%, the range of variation decreases, resulting in C_v being smaller than that found for topsoil. This is because of the more favorable ratio between water revenue and ET. At all studied depths, the increase in the amount of the irrigation rate has a positive effect in the direction of stabilizing the soil moisture values. It is also clear from the graph that the influence of the irrigation rate is much stronger than that of the thickness of the soil layer.

A) soil layer of different thickness

B) layer by layer in a depth of 20 cm

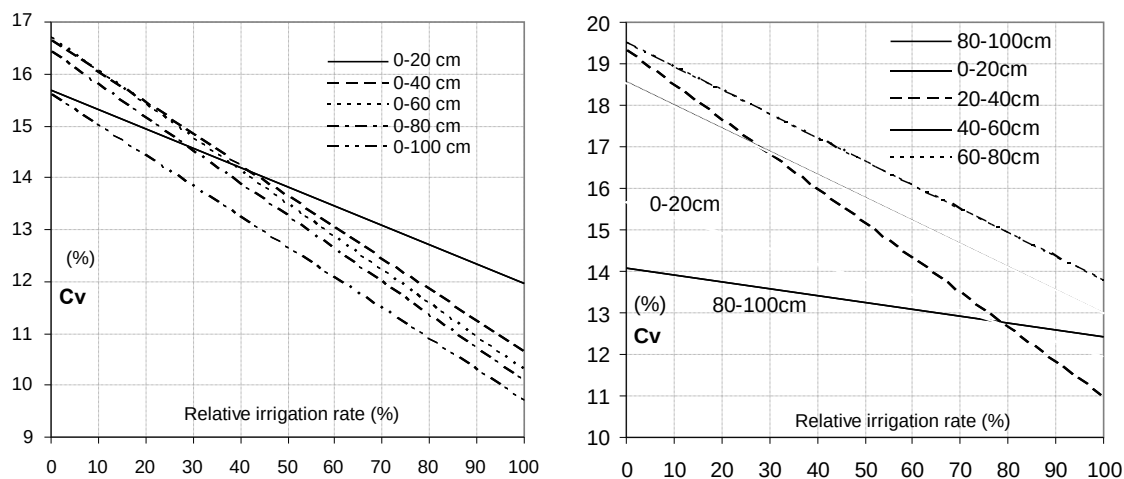


Fig. 7. Influence of the irrigation regime on the variation of the water supply and soil moisture layer by layer

The second graph (B) shows the influence of the irrigation rate on the variation of humidity in the different parts of the one-meter soil layer. The steeper the line, the more sensitive this soil layer is to the amount of irrigation rate, i.e. the step by which C_v decreases is larger. The 20-40cm layer reacts most sensitively, due to the fact that all norms from 50% and above affect it by maintaining relatively high soil moisture. On the other hand, under non-irrigated conditions and under irrigation with small rates, there is mainly water consumption from this layer, as a result of which the humidity varies. That is why, under these conditions, C_v is very high, and in case of irrigation with large rates, it is the lowest (difference of 7.5%). The 80-100cm layer almost does not change, because the irrigation water does not reach it, the influence of external factors is practically absent, and the part of the root system in this layer is the smallest. Moreover, this layer is very rarely moistened by vegetation precipitation. The minimal influence of the irrigation regime on this layer can be explained by the cases when there is an uneven distribution of moisture in the upper layers, combined with drought in some of them. If in these cases the 80-100cm layer has easily accessible water, the plants use it, but not equally, i.e. those irrigated with higher rates are better developed and with greater possibilities for assimilating water from this layer. However, the differences are very small, which is clearly visible in the graph. In the 40-60 and 60-80cm layers, C_v changes with approximately the same step, but significantly, which proves the influence of the size of the irrigation rate in this part of the soil profile as well.

Distribution of water in the soil profile during irrigation by supplying the irrigation water in each row and inter-row.

Figures 8 and 9 show the contours of soil moistening after the first watering, but in years with different rainfall in the autumn-winter and early-spring periods.

A significant difference is observed in the deeper soil layers, as their water consumption is significantly lower. In the 0-50cm layer, where the main part of the root system of the plants is located during the period of flowering and pod formation (the time for the first watering), the situation in the two experimental years is similar. In both cases, significant differences in wetting contours are observed between the two methods of irrigation water distribution on the soil surface.

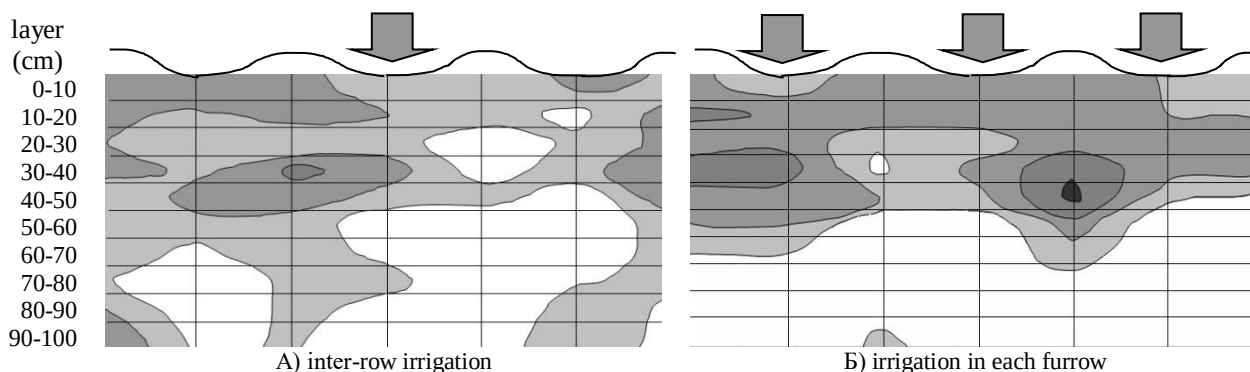


Fig. 8. Contours of soil moisture after the 1st irrigation (2003, variety Biser)

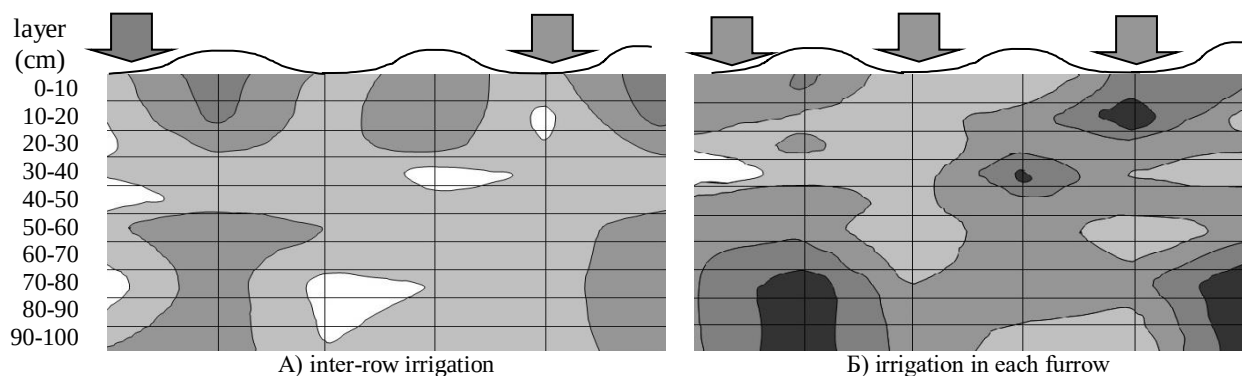


Fig. 9. Contours of soil moistening after the 1st irrigation (2004, variety Biser)

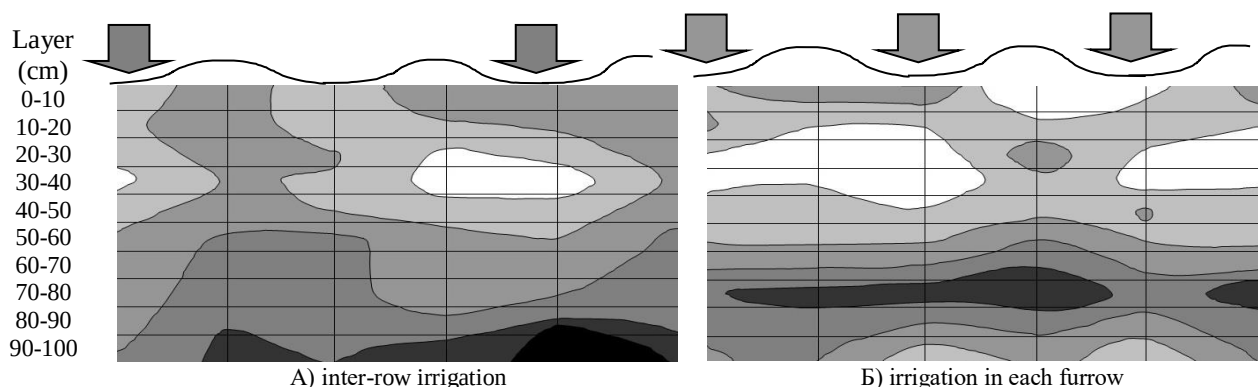


Fig. 10. Contours of soil moisture after the 2nd irrigation (2004, variety Biser)

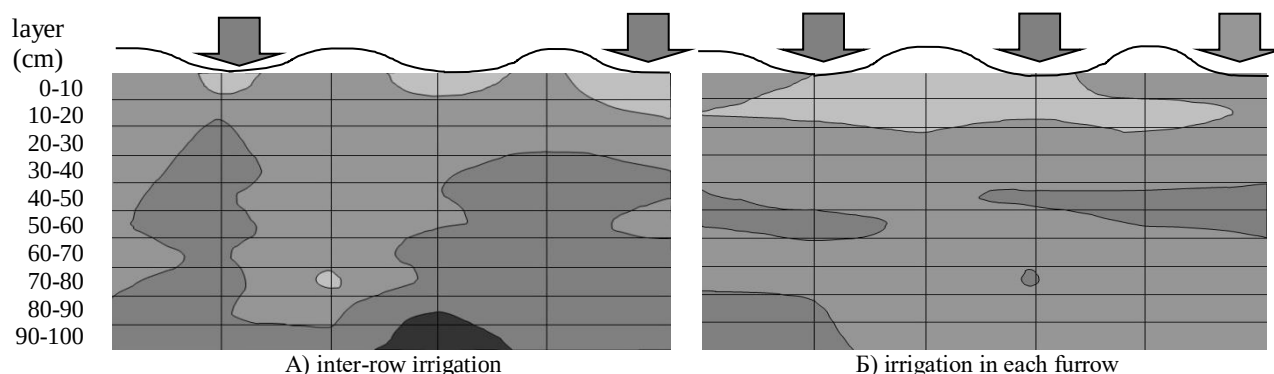


Fig. 11. Soil moisture contours after the 3rd watering (2008, Srebrina variety)

Legend:	over 90%FC	80-90%FC	70-80%FC	60-70%FC	50-60%FC	under 50%FC
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When the first watering is applied, a more favorable distribution of water in the soil profile is observed with inter-row irrigation. This is so because at the moment there is no accumulated water deficit, as a result of which the supplied irrigation rate manages to reach a greater depth and at the same time be distributed in a horizontal direction (graphs A). The presence of very high humidity in depth makes it possible to connect the irrigation water with that available in the 50-100cm layer, which affects the distribution of water in the upper layers (fig. 8.A). When the irrigation water is supplied in each furrow, the soil is moistened at a significantly smaller depth, which is why such an interaction (between irrigation water and available water supply in depth) is not observed. However, the consumption of water by the plants is approximately the same in both cases, which is why the 0-50cm layer dries faster. If it is necessary to analyze the distribution of the water from the first irrigation in the two ways of its implementation, the graphs from Fig. 9 are more indicative, since the soil moisture in depth is lower. When supplying inter-row irrigation, soil moisture optimization is observed in the entire one-meter soil layer under the moistened furrow, while taking into account the positive effect of infiltration. Thus, one week after the first watering the conditions are very favorable throughout the soil profile. Soil drying (slight to moderate) was observed in the area immediately below the plants due to the high concentration of roots (Fig. 9.A). When moistening each furrow, a more substantial and uneven distribution of water in the soil profile is observed. Considering the intensity of water consumption during this phase, it can be

considered that a large part of the irrigation water was used, as a result of which the zones with optimal humidity (over 80%FC) occupy a small relative share within the studied profile (Fig. 9. B). From here, it can be concluded that more favorable conditions are created when applying the first irrigation inter-row. Fig. 10 shows the results for the distribution of the irrigation water in the soil profile, after the implementation of the second irrigation. Here, the exact opposite is observed – with inter-row irrigation, a more intense depletion of water is observed, compared to irrigation in each furrow. Nevertheless, it can be considered that one week after the second irrigation, the conditions for the inter-furrow-irrigated plants are favorable, since there are significant areas with humidity above 80%FC, and those with humidity between 70 and 80%FC cannot cause significant disturbances in plant development. Between the second and third irrigations, intensive depletion of water continues, as a result of which the subsequently reduced irrigation rate has a far weaker effect, compared to the previous two. This applies to both technologies for the distribution of irrigation water on the surface of the field (fig. 11). A week after the third irrigation in both variants, a significant decrease in humidity was observed in the active soil layer of soybeans. When irrigating in each furrow, the drying is more uniform, and the intensity is weak in the 20-40cm layer, to moderate in the 40-60cm layer. In the surface soil layer, where the irrigation water is distributed, the humidity is still within optimal limits, but this is a consequence of the deficit during the previous inter-irrigation period. When watering inter-furrow, a reorientation of the root system of the plants in the direction of the moistened interstices is observed. The intensity of water use from this area and the associated drought is increasing.

Influence of irrigation regime on the growth dynamics of soybean

• Plant leaf weight

Regardless of growing conditions, plants in both cultivars achieved the greatest leaf biomass during the period of seed development (R5). Canceling watering during the period of intensive leaf formation has a very significant negative impact. Subsequent resumption of irrigation until the end of the irrigation period cannot compensate for the effects of drought during the mass flowering and pod formation period. The least negative effects on leaf mass were observed when irrigation was canceled during the pod-filling period, but high values remained for a shorter period of time, i.e. in addition to developing stronger foliage, the better water regime also keeps it for longer.

• Weight of plant stems and branches

From the analysis of the experimental data, it is clear that regardless of the irrigation regime and conditions of the year, soybean stems increase their biomass until the end of the R5 phase. After that, it remains a relatively constant value, no matter what the soil moisture is. The attainment of this maximum coincides in time with the maximum of the leaf mass, giving reason to consider that at this time the vegetative growth of the plants ends. The conditions of the year affect the number of irrigations, and they, in turn, affect the effect of the applied irrigation rates. In all other cases, the increase in the size of the irrigation rate increases the weight of the stems.

• Pod weight dynamics

According to the data from the experiment, the increase in the weight of the pods continues until the beginning of R7, but already in R6, its intensity begins to gradually slow down. For the formation and retention of the maximum number of pods on the plants, soil moisture during the R1-R4 period is important. During the R5-R6 period, a significant share of the mass of the pods begins to be occupied by the growing seeds, and the influence of the irrigation regime becomes more and more pronounced. That is why it is considered that the moisture supply of plants during this phenophase is extremely important for the quantity and quality of the yield. Under non-irrigated conditions, the deficit during this part of the vegetation is most often moderate – to strong, while under irrigation, it is partially compensated for the smaller rates, and neutralized to a significant extent or completely for the large ones. Thus, larger differences between different irrigation regimes are formed in years with more intense droughts in August.

Influence of the irrigation regime on basic photosynthetic indicators in soybean

• Influence of the irrigation regime on the leaf area (LA) of soybean

The leaf area of soybean changes in parallel with the leaf mass within a specific year, variant and variety (Fig. 12). This means that both indicators are influenced in the same way and to the same degree by environmental factors and the applied irrigation regime, i.e. there is a mathematical relationship between them. It is linear at $R^2=0.968$. The equation is as follows: $LA=227.4+200m$ (cm^2/p), where **LA**

is the leaf area of a plant, and **m** is the dry mass of the leaves corresponding to this leaf area. Variants of the relationship are proposed, by means of which the LA for 1m² can be calculated, 1da and 1ha.

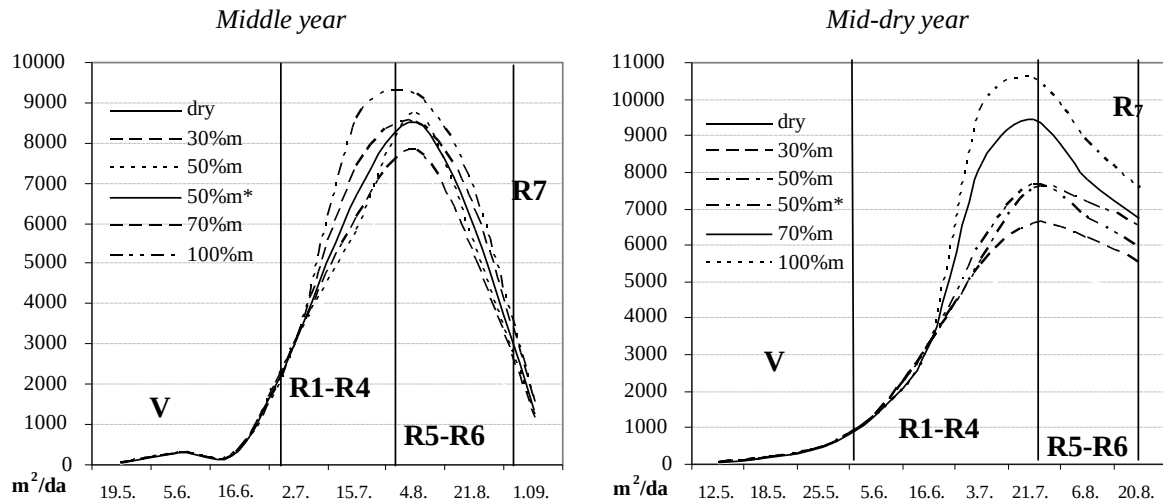


Fig. 12 Change in the LP of soybean depending on the irrigation regime

Against the background of the different levels of water supply, the temperature factor, expressed by accumulating the values of the midnight and the effective air temperature, plays a major role in the formation of the leaf area in soybeans. Between them there is a close power relationship of the type $Y=ax^n$, which is expressed graphically by means of a convex parabola. The parameter **a** indicates the necessary temperature sum (°C) for the formation of 1m²/m² LP, and **x** is LP (m²/m²). The irrigation regime affects the relationship parameters, but it depends to a much greater extent on the biological characteristics of the culture, therefore it demonstrates approximately the same character for all varieties and irrigation regimes. As the water regime of the plants improves, the temperature sum required for the formation of a given leaf area gradually decreases. This is expressed by lowering the power of the equation. As the vegetation progresses, the differences between irrigation regimes regarding the requirements for ΣT° for the formation of a certain LA gradually increase. The relationship based on ΣT° and $\Sigma T^\circ_{\text{eff}}$ demonstrated approximately the same accuracy $R^2 > 0.91$. From a practical point of view, it can be used to predict when the crop will reach a certain leaf area.

• **Influence of the irrigation regime on the leaf area index (LAI)**

LAI depends on the applied irrigation regime, on the meteorological conditions of the year, and to a lesser extent, on the varietal characteristics. Under non-irrigated conditions, it varies widely - between 56 and 86% of that - under optimal irrigation. Its values are influenced by precipitations and irrigation, determining the level of soil moisture until the end of phase R4 or the beginning of phase R5. The effect of irrigation with small irrigation rates (25-30%) in the absence of precipitations is relatively small (1-19%). A more significant increase in LAI can be ensured at a rate of 50%, (up to 28%) and there is practically no difference in inter-row and each furrow irrigation. Irrigation with a rate of 70-75% provides a very high LAI, varying between 89-99% of the maximum. These data show that the LAI does not change in proportion to the change in irrigation norms. A linear relationship was established between LAI and soil moisture in the 0-60cm layer, referring to the period R1-R6, with $R^2=0.704$. It can be used to predict the size of LAI, depending on the level of soil moisture.

• **Influence of irrigation regime on FSP of soybean**

Soybean FSP grew fastest during the (R2-R) period. Maximum values are reached in the time between the end of phase R4 and phase R5, and the irrigation rate does not affect the time of occurrence of the maximum, but only its values. With the increase in irrigation rates, the duration of functioning of the leaf apparatus is extended, as a result, the period with high FSP values also increases. The reduction of irrigation rates by 25-30% provides a very high FSP of the soybean crop, amounting to about and over 90% of that - with optimal irrigation (on average 95%). Applying small irrigation rates showed a weak positive effect on FSP, varying between 3 and 14%. There is a linear relationship between FSP and plant biomass, with $R^2=0.77$. The equation is as follows: $m_p=3.82FSP+62.9$ (kg/da). This dependence

confirms the opinion that the parameters of the photosynthetic leaf apparatus of soybean represented by FSP have great importance for the amount of accumulated plant biomass, part of which is the yield.

• ***Influence of the irrigation regime on the net photosynthetic productivity (NPP) of soybean***

The work of the leaf apparatus is most fully and accurately expressed by the accumulation of biomass for a certain period of time, which represents the net productivity of photosynthesis (NPP) or the so-called net photosynthesis. It represents the accumulated dry mass (g) for a certain time (24h), referred to as a unit of area (1m²). The size of the irrigation rates affects the NPP in soybeans, and there is a relationship between them that differs during the different phenophases (Fig. 13). NPP and its intensity are directly related to phenological development, i.e. its distribution by organs is also different during the different periods of the soybean vegetation. Irrespective of the irrigation regime, the NPP in the leaves, stems and roots is maximum during the vegetative period, after which it decreases, reaching zero values during the seeding period - R6. In pods, NPP increased most rapidly during the R3-R4 period, continuing to increase through R5, but at a slower rate. During R6 and R7, due to the rapid reduction in leaf area, photosynthetic activity also rapidly decreases, affecting the values, but nevertheless, values of 1.4 to 2.4g/m².day (absolutely dry matter) were measured in beans during this part of the growing season.

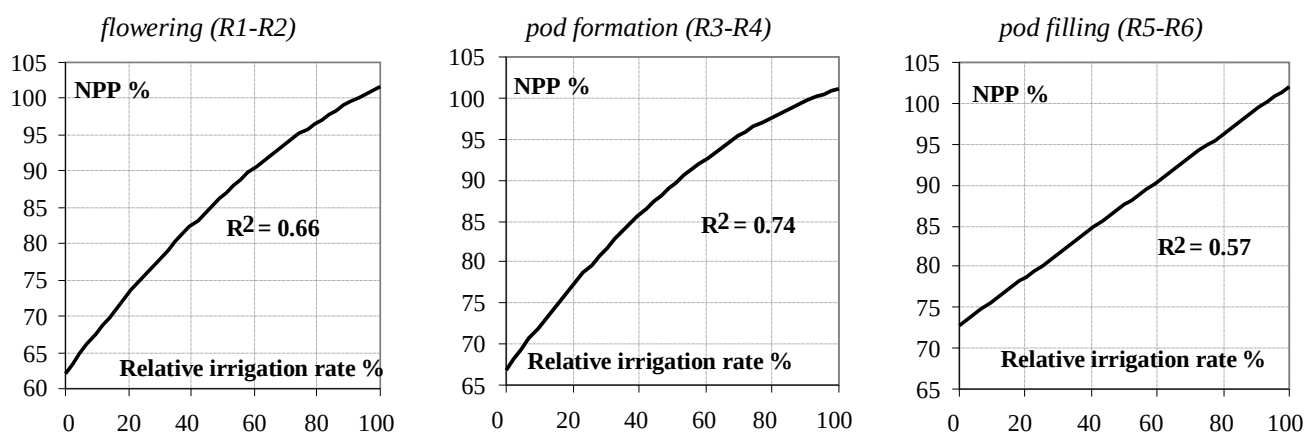


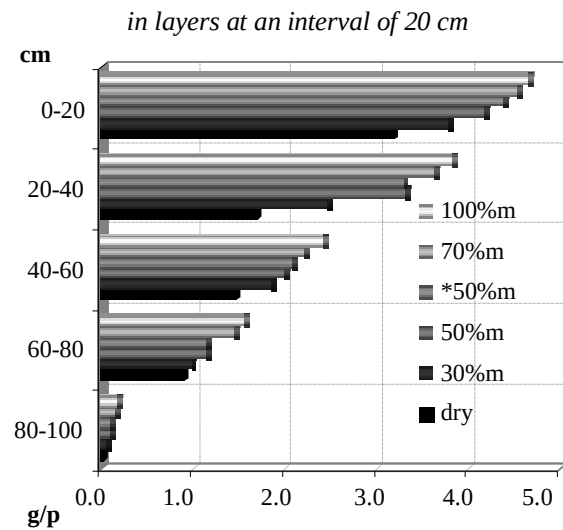
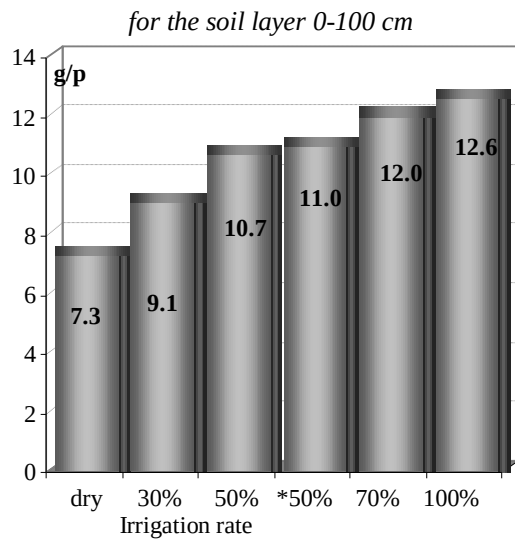
Fig. 13. Relationship between the irrigation rate and the NPP by phenophases

Irrigation regime affects the NPP in all plant organs, but certain differences still exist. In the case of leaves, the strongest influence of the irrigation rates is during the period of flowering and the beginning of bean formation, while in the case of the stems, an effect of the rates is observed in all irrigations applied. The NPP in the roots is more sensitive during the pod formation period. In the pods, irrigation significantly increased the NPP at the beginning of the pod formation phenophase, but the difference between the variants started to become visible in the second half of the period (R4). The cumulative effect of applying a different watering regime after the second and third irrigations makes the differences during the pod-filling period even more significant.

Until the appearance of the branches, on average, 60% of the productivity of photosynthesis is related to the growth of the leaf mass, and 28% is in the direction – of the formation and growth of the stem. 12% of it is directed to the roots. During the next phenophase, a part of the NPP is redirected from the leaves to the stems and branches, resulting in a change in the ratio between them (55 to 34%). The irrigation regime does not have any effect on the relative distribution of NPP by organs during the period R1-R2. During the period R3-R4, a significant part of the PPF is redirected to the pods, which changes the other three components. During the R5 period, the irrigation regime had a weak positive effect on PPF in leaves, roots, and stems. At the same time, more than 55% of the PPF is oriented toward the pods, and more precisely – for the development of the seeds and the increase of their biomass. Phase R6 remains outside the irrigation season, but it is possible that there is a residual effect of irrigation carried out in the previous phases and the amount of irrigation rates. In terms of PPF, this effect can only be found in beans, since it is zero in other organs.

Effect of irrigation regime on the soybean root system.

The irrigation regime has a significant influence on the root weight in the entire range of the one-meter soil layer, and even small irrigation rates are able to increase their dry mass by nearly ¼. Applying higher irrigation rates further increased root weight by between 64 and 73% (Fig. 14).



Soil layer	dry	30% <i>m</i>	50% <i>m</i>	*50% <i>m</i>	70% <i>m</i>	100% <i>m</i>
0-20 cm	3.195	3.766	4.175	4.375	4.531	4.658
20-40 cm	1.709	2.452	3.313	3.284	3.623	3.825
40-60 cm	1.471	1.844	1.992	2.081	2.203	2.414
60-80 cm	0.906	0.985	1.141	1.136	1.464	1.555
80-100 cm	0.038	0.056	0.098	0.105	0.162	0.175
0-100 cm	7.319	9.103	10.719	10.981	11.983	12.627

Fig. 14. Dry mass of the root system (g/p) by soil layers and depending on the irrigation rate (Biser variety)

The main part of soybean roots, regardless of the irrigation regime, is located in the surface soil layer 0-20cm (37-44%). Most of it is in the 10-20cm layer. This regularity does not depend on the irrigation regime. It is biologically predetermined. As the water supply of the plants improves, a clear tendency is observed to decrease the share of roots in 0-20 cm compared to those in the one-meter layer. It is against the background of increasing absolute values and is due to a change in weight in the lower layer 20-40cm, where the trend is exactly the opposite. In this soil layer critical for soybean plants, 23% of the roots of non-irrigated soybeans are formed and 30-31% at irrigation rates in the range of 50-100%.

There is a close relationship between root weight and irrigation rate, which is quadratic at $R^2 > 0.97$. Its parameters are specific for each soil layer (fig. 15). The distribution of the root system by soil layers provides valuable information regarding the determination of the amount of irrigation rates and the depth at which the soil should be moistened. If irrigation rates are calculated to moisten the 0-40 cm layer, it should be taken into account that irrigation will provide up to 67-70% of the entire root system of the plants. If the rates are calculated for the 0-60cm layer, at optimum soil moisture between 86 and 89% of the root system will develop. This means that the criterion for the irrigation schedule should be soil moisture in 0-40cm, and the irrigation rates should be such that they moisten the layer 0-60cm.

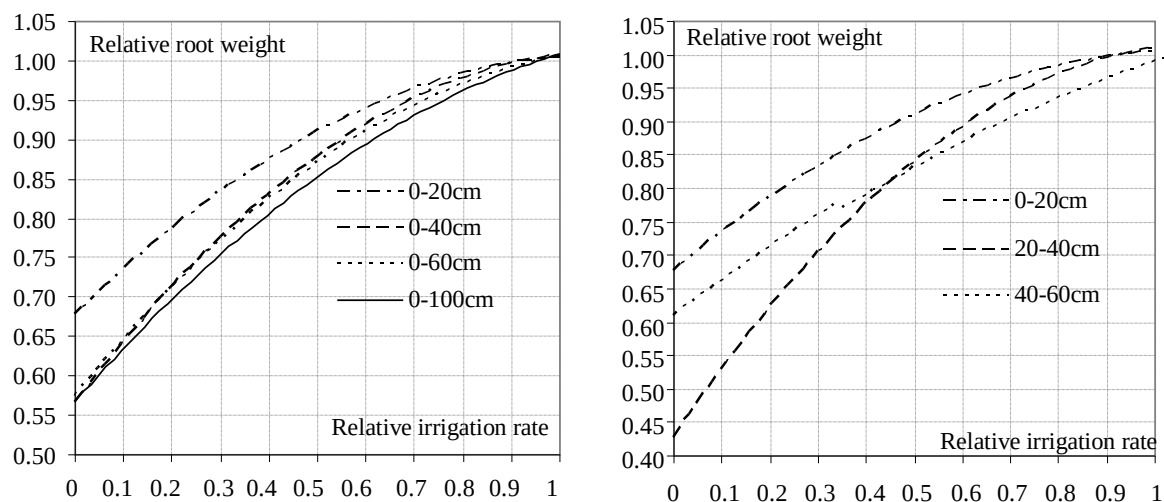


Fig. 15. Relationship between the relative weight of the roots and the irrigation rate by soil layers

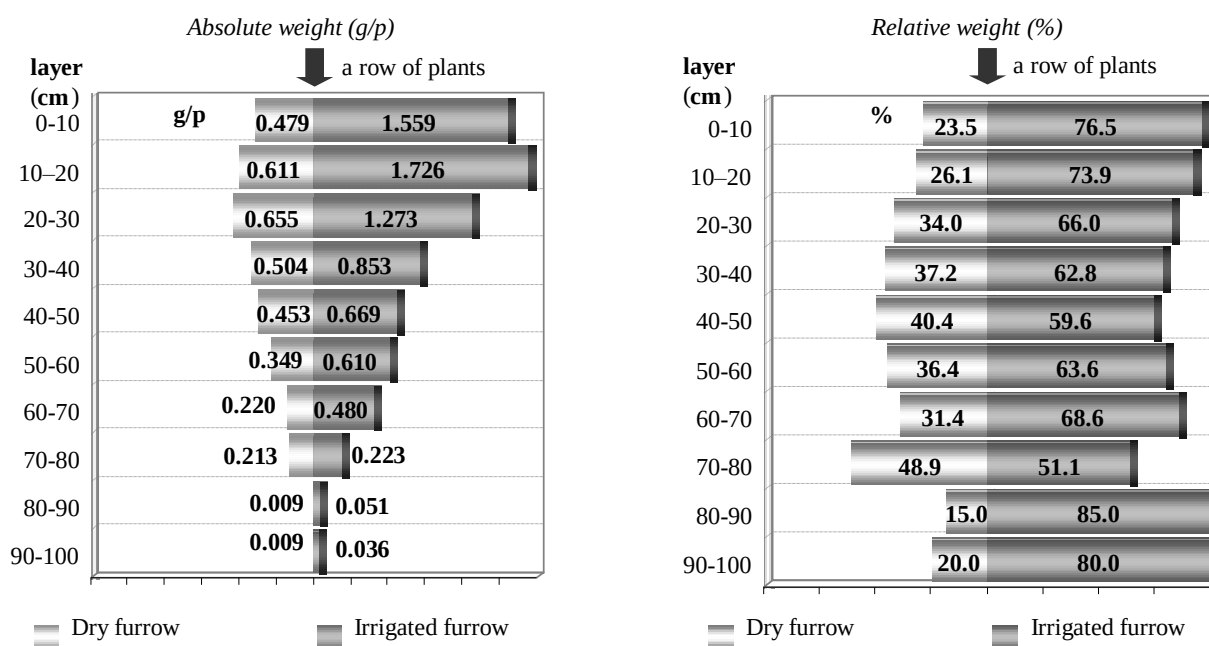


Fig. 16. Distribution of the root system of the soybean (Pearl variety) in depth, at a rate of 50% and supplying the irrigation water through the inter-row

Irrigation through the furrow leads to a redistribution of the root system in the direction of the wet furrow, with the ratio of roots from both parts of the row being 3:1 for 0-20cm and 2:1 for 20-60cm, respectively (fig. 16). In the deeper layers of the soil, where irrigation rates have no influence, the ratio is variable and does not follow a specific logic. There is a tendency to increase the share of roots in the dry furrow at a depth of 20-50cm. This is because water infiltration is better expressed in this layer of the soil, compared to the surface (0-20cm), i.e. part of the irrigation water enters under the dry furrow and improves to a certain extent the conditions for the development of the roots. In terms of total root biomass, the difference between the two technologies is about 1%.

Soybean evapotranspiration

Evapotranspiration (ET) of soybean was determined under non-irrigated conditions, under optimal irrigation, and under irrigation with reduced irrigation rates.

Daily values of evapotranspiration

Fig. 17 shows the daily trend of ET in soybeans, depending on the irrigation regime, on average for the experimental period. The graph gives a generalized and at the same time reliable idea of the dynamics of this indicator within the entire one-meter soil layer. The influence of three groups of factors is taken into account - biological, abiotic, and degree of water supply (irrigation regime).

•**Biological factors:** The daily trend of soybean ET is described by a single-peaked curve representing a convex parabola, with a maximum during the period of bean formation (R3-R4). In very

rare cases, it may be just before R3 or at the beginning of R5. This trend is determined by the plants' different needs for water during the growing season. Thus, until the appearance of the first branches, ET has low values, because the leaf area is small, the meteorological situation is "calm", and the plants only increase their vegetative biomass. At the appearance of branches, the intensity of ET begins to gradually increase, and with the beginning of flowering, the values go up rapidly. This is characteristic of the beginning of the reproductive period of all agricultural crops, and in the case of soybeans, it continues until the maximum is reached during the period of bean formation. Until the end of the phenophase, the values can remain high, depending on the growing conditions, but due to the ensuing slowdown of the life processes in the plants, senescence, and gradual loss of leaves, the intensity of ET during the pod-filling period begins to decrease, regardless of that environmental conditions suggest intense evaporation (high air temperature combined with low atmospheric humidity).

- *Climate factors and meteorological conditions:* This group of factors can slightly affect the biologically determined trend of ET. Values can vary in a certain range, and the period of the maximum can be changed (earlier or later) by no more than one decade. The trend of ET can be partly influenced by the different date of sowing.

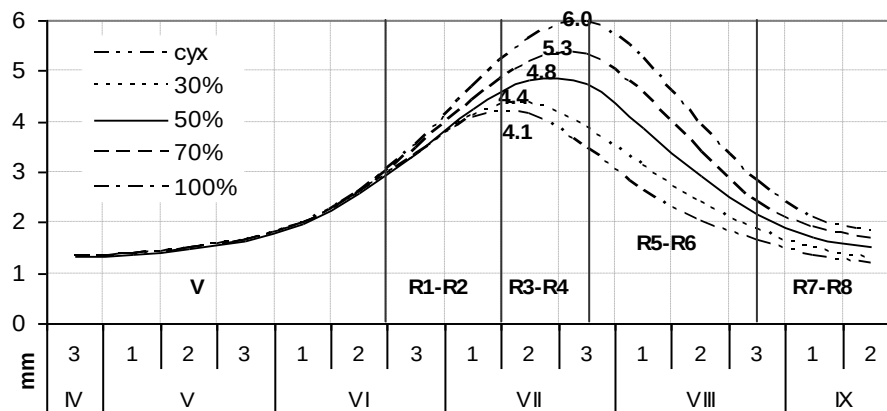


Fig. 17. Daily ET by variants on average for 2003-2009

- *Influence of the irrigation regime:* Under non-irrigated conditions, maximum values of about 4.0 mm per day are reached during the first or second decade of July in phase R3 (beginning of bean formation). Due to the depletion of a significant part of the available water in the soil, as well as due to the beginning of senescence and death of part of the leaves, ET rapidly decreases its intensity, reaching the initial values during the maturing period. Irrigation with small irrigation rates (up to 30% of the maximum calculated) does not significantly change the trend of ET. The values increase slightly, without changing the time of the maximum (R3), which is 4.4mm on average. The small difference compared to non-irrigated soybeans is due to the fact that these irrigation rates increase soil moisture for a short time and only in the 0-20cm layer. Applying ½ of the maximum irrigation rate increases the ET values more significantly, because in addition to the 0-20cm layer, part of the 20-40cm layer is also moistened. The effect of this irrigation rate is more prolonged and leads to a displacement of the maximum (average 4.8mm) about 5 days later, falling in the second or third decade of July, during the period of intense bean formation. With irrigation at a rate in the range of 70-100%, the daily real ET reaches its greatest intensity, and the maximum (5-6mm) is at least a decade after that under non-irrigated conditions. Moistening the soil to a depth of 40 – 60 cm (respectively for the two irrigation rates) extends the time of high ET intensity, because the leaves are fresher and remain on the plants for a longer period of time. Each watering has a different meaning for the course of ET, depending on the period in which it is applied. The results of the study show that the maximum value is influenced by irrigation only until the beginning of the phenophase bean formation (R3). Watering during pod formation and after can only keep values higher for longer. The maximum difference between the daily values of ET for the different irrigation regimes is not during the period of the maximum, but 1-2 decades later, since the effect of irrigation is not instantaneous. In addition, each subsequent watering with a reduced rate leads to an ever-increasing water deficit, which is directly related to the intensity of ET.

Soybean evapotranspiration by periods (phenophases)

The results under non-irrigated conditions are presented graphically in Fig.18.

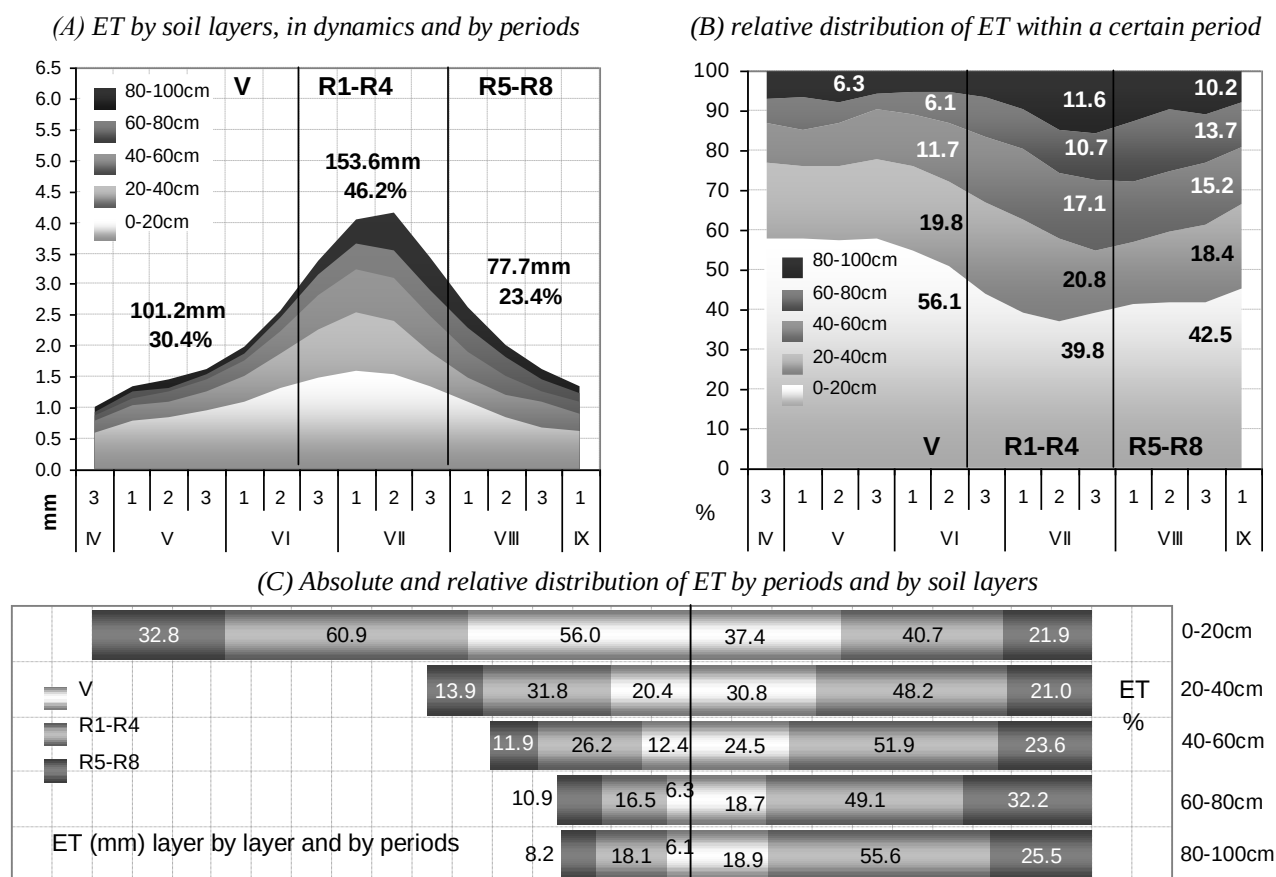


Fig. 18. Distribution of ET of soybean (Biser variety) by periods and by soil layers under non-irrigated conditions

ET during the vegetative period of soybean is mainly concentrated in the 0-20cm layer (over 50%). During this period, a significant part of the total ET is formed, which is a result of its longer duration. Its relative share depends on the conditions and ET in the next two periods. The period of flowering and pod formation is characterized by the most intense ET in the entire range of the one-meter soil layer. The relative share of the surface layer decreases, while that of the layers below 40 cm depth increases. As the depth increases, the participation of ET during the vegetative phase decreases and the relative share of the phenophases forming the reproductive period increases. Irrigation is a major factor influencing evapotranspiration. It could change to some extent its distribution between soil layers and phenophases, and here the size of the irrigation rate, the number of waterings and the time of their implementation are important.

The impact of irrigation is mainly in the area where the irrigation water reaches, i.e. changes directly affect only this layer. The intensity of ET increases, and the maximum is 1 decade later, compared to the layers lying below, where the irrigation water does not reach. In all irrigation regimes and periods of vegetation, the 0-20cm layer is of leading importance, where irrigation with reduced irrigation rates has a higher relative share compared to 20-40 and 40-60cm combined. With optimal irrigation (fig. 19), ET is activated in the 20-60cm layer and during the reproductive period its relative share reaches and even exceeds the share of the surface soil layer (0-20cm). The maximum in the entire range of 0-100cm displace in the third decade of July, i.e. it is at the same time in all soil layers. When applying this irrigation regime, an average of 88% of ET is formed in the 0-60cm layer for the entire one-meter layer (within the period), and 86% during the flowering-bean formation period. During the pod-filling and maturing period, this relative share is average 87%, considering that this same layer contained just over 86% of the soybean root system.

(A) ET by soil layers, in dynamics and by periods

(B) relative distribution of ET within a certain period

Annual ET data is important in terms of how well natural water sources cover plant needs, how varying water availability changes water consumption, and how this affects yield. The data for the annual ET by variants and years is presented in table 7. They are typical for soybeans and in sync with those reported by our authors for other regions of the country.

Table 7. Annual evapotranspiration of soybeans (Biser and Srebrina varieties) depending on the irrigation regime

Irr.rate (%)	ET (mm)	to dry		to optimum		ET (mm)	to dry		to optimum		
		±	%	±	(%)		±	%	±	%	
2003						2004					
cyx	292	St.	100	-142	67	365	St.	100	-118	76	
30	337	45	115	-97	78	421	56	115	-62	87	
50	356	64	122	-78	82	446	81	122	-37	92	
70	378	86	129	-56	87	457	92	125	-26	95	
100	434	142	149	St.	100	483	118	132	St.	100	
2005						2006					
cyx	399	St.	100	-38	91	319	St.	100	-115	73	
30	411	12	103	-26	94	320	1	100	-114	74	
50	427	28	107	-10	98	369	50	116	-65	85	
70	428	29	107	-9	98	409	90	128	-25	94	
100	437	38	110	St.	100	434	115	136	St.	100	
2007						2008					
cyx	346	St.	100	-155	69	277	St.	100	-106	72	
30	353	7	102	-148	70	306	29	110	-77	80	
50	410	64	118	-92	82	334	57	121	-49	87	
70	465	119	134	-37	93	361	84	130	-22	94	
100	501	155	145	St.	100	383	106	138	St.	100	
2009						average 2003-2009					
cyx	327	St.	100	-154	68	332	St.	100	-118	74	
30	357	30	109	-124	74	358	26	108	-92	80	
50	382	55	117	-100	79	389	57	117	-61	86	
70	419	92	128	-62	87	417	85	126	-33	93	
100	481	154	147	St.	100	450	118	136	St.	100	

The study of the distribution of ET (relative and absolute) between the different soil layers provides information about the depth to which plants actually use water and in which layer the main part of soybean water consumption is concentrated. This data is useful in specifying the range of the estimated soil layer (the depth of wetting under irrigation). As already established, the 0-20cm layer has a leading role in soybean ET, and this applies to every phenophase of the vegetation, regardless of the irrigation regime and the conditions of the year. With increasing depth, the participation of different soil layers changes, usually decreasing. In addition, it depends on the conditions of the year and the irrigation regime. For the conditions of the present study, the layer-by-layer distribution of ET was established, and the results are presented in Fig. 20.

(A) Absolute values

(B) Relative values

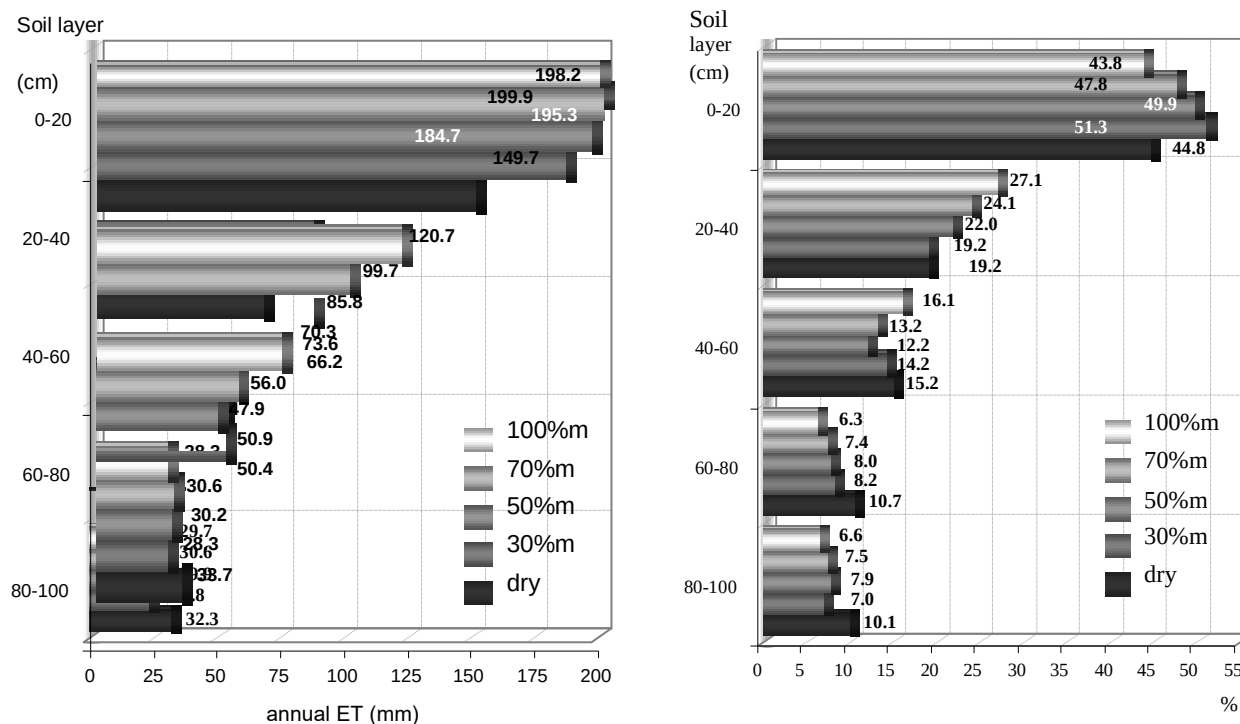


Fig. 20. Layer-by-layer distribution of ET depending on the irrigation regime - averaged data

Participation of precipitation, irrigation rate and initial water supply in the formation of the total ET

Under non-irrigated conditions, ET in all agricultural crops (including soybeans) is formed from the water accumulated in the soil during the autumn-winter and early-spring period, as well as from the usable part of the vegetation precipitation. Under irrigated conditions, the irrigation rate is added to these water revenues.

Participation of vegetation precipitation in the formation of ET

For the climatic conditions of our country, vegetation precipitation provides a significant part of the water consumption of agricultural crops, including that of soybeans. Fig. 21 presents averaged data on the relative contribution of precipitation, the irrigation rate and the initial water supply in the formation of ET. The results confirm the leading role of precipitation, as there is a clear tendency to decrease their relative share with an increase in the amount of irrigation rates. However, the average relative share of precipitation, even with optimal irrigation, exceeds 40%.

Participation of the irrigation rate in the formation of ET

The irrigation rate participates in the formation of ET depending on its size and the depth to which the irrigation water reaches. On average over 8 years, its relative share increased from 13.3% at the lowest rate to a significant 35.1% at optimal irrigation.

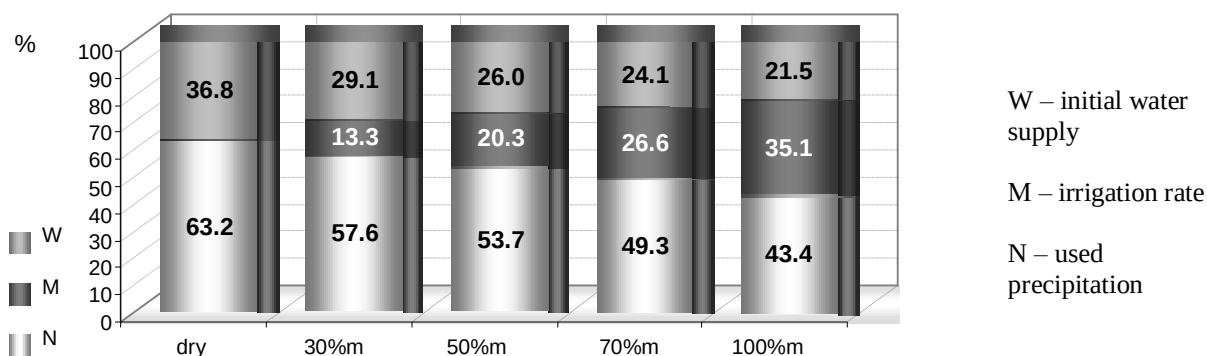


Fig.21. Formation of ET in soybean by variants, averaged over the experimental period

Participation of the initial water supply in the formation of ET

The initial water supply is essential in the formation of the ET of each crop, including and soy. On average for the experimental period, it provides about $\frac{1}{3}$ of the ET in the one-meter soil layer in the

non-irrigated soybean. Irrigation does not nullify the importance of the initial water supply, but lowers its relative share, ie. the higher the irrigation rate, the lower this share. Thus, at a rate of 50-70(75%)%m, it has a participation in ET comparable to that of the irrigation rate, and with optimal irrigation it participates with the lowest share, compared to the other two components. This trend was observed in all experimental years, and in middle and wet years its relative values were lower in all irrigation regimes, compared to those in mid-dry and dry years.

Seed yield depending on the irrigation regime.

In the course of the comparisons and analyses, the hypothesis emerged that the amount of soybean yield depends mainly on the number of beans per plant and the fully developed seeds in them, as well as to a certain extent on their absolute mass. The correctness of this hypothesis can be tested by looking for a relationship between yield and the assumed two main factors on which it depends. The conducted experiments offer a sufficiently large number of data (values), which is why the obtained relationships are sufficiently correct and representative. Fig. 22 shows the relationship between the number of beans per plant and the mass of seeds in them, and in the first graph (A) it is in relation to the mass of all available seeds (the potential yield), and in the second (B) - in relation to ratio of fully developed seeds (real yield). The high values of R^2 (respectively 0.872 and 0.799) are proof of the correctness of the first assumption. Regarding the fully developed seeds, the coefficient of determination is slightly lower, but this is due to the different influence of the applied irrigation regimes on the degree of seed development. However, both graphs confirm the close relationship between the number of pods per plant and seed yield (potential and actual). The two equations presented can be used to predict seed yield towards the end of the pod formation phase.

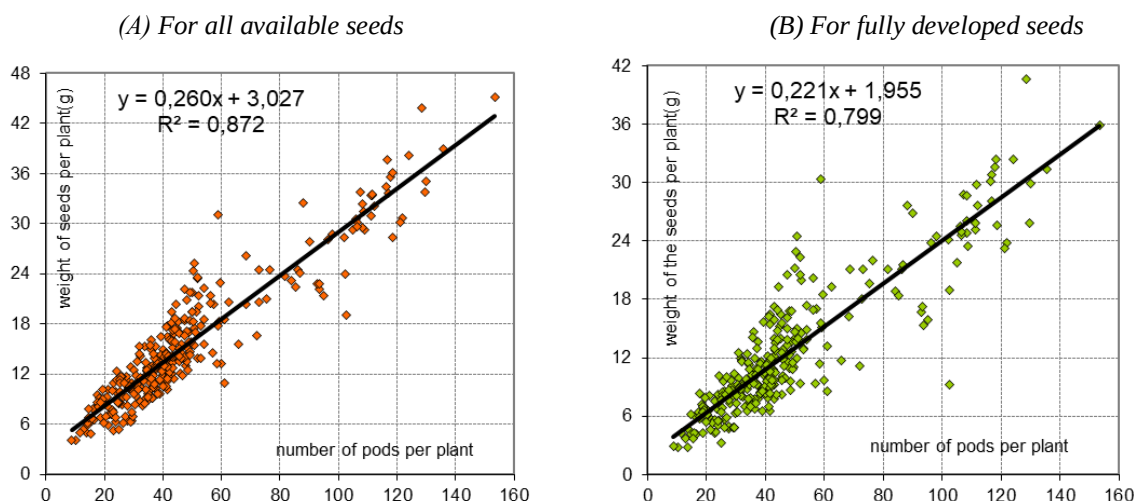


Fig.22. Relationship between number of pods and seed weight per plant

A relationship was established between the number of seeds per 1 plant and their mass (real yield). According to the graph in Fig.23, it is linear at $R^2 > 0.9$. Considering that this result was achieved on the basis of a very large number of experimental points, it can be confidently stated that the yield of soybeans depends mainly on the number of fully developed seeds per plant and, accordingly, on a unit area.

The following graph (fig. 24) verifies the credibility of the next (third) assumption, regarding the influence of the absolute seed mass on soybean yield. The results show categorically that this indicator is not decisive for the size of the yield, regardless that the irrigation regime under certain conditions can influence the mass of 1000 seeds. Increasing the absolute mass of soybean seeds does not increase the yield, there is even a tendency towards its decrease. This is explained by the fact that experimental data from all variants were used to establish the existence of such a dependence. In a significant number of cases, however, the plants have large and heavy seeds, but a smaller number per plant, therefore a lower yield. In the other cases, the opposite trend is observed. This means that in the first case the absolute mass may have a certain positive influence on the yield, and in the second - a negative one. When all these points are placed simultaneously in the coordinate system, their dispersion is very large, which is

visually observed and confirmed at the same time by the extremely low value of R^2 , according to which the sought dependence does not exist, and the third assumption is rejected.

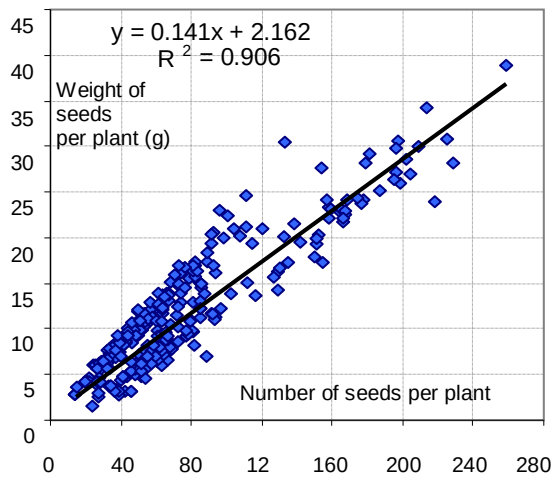


Fig.23. Relationship between number of seeds and yield per plant

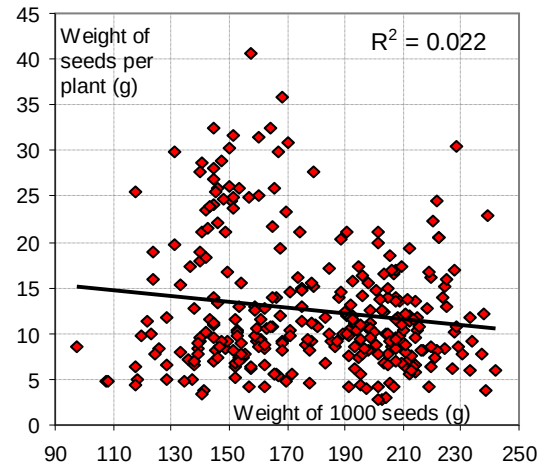


Fig.24. Relationship between absolute seed mass and yield from 1 plant

The yield of seeds from one plant is determined subjectively, but it is a direct reflection of the conditions under which the vegetation of the plants selected for the purpose takes place, including the influence of the irrigation regime. The logical sequence in the formation of the yield from one plant is as follows: number of internodes → number of fertile flowers → number of beans → number of seeds. The remaining structural elements of yield can influence the listed four indicators, with the final result being the number of seeds and, respectively, the actual yield. This conclusion was made as a result of the analyzes of the influence of the irrigation regime on the yield components. This mechanism of soybean yield formation has been verified and analyzed based on the data from all variants of the experiment. The results show the following:

• **Positive influence of the different irrigation regimes - comparison with the results under non-irrigated conditions.**

Optimal irrigation: The application of an optimal irrigation regime by maintaining the soil moisture in the 0-60cm layer above 80%PPV greatly affects the vegetative components of the yield, since the first two irrigations are most often carried out during the flowering-bean formation period, when the plants develop intensively its vegetative part. The number of internodes on the central stem and on the branches increases significantly, thereby maximizing the productive potential of the plants. The number of branches and the height of the first bean do not change unidirectionally under the influence of irrigation, but the develop of the branches is better. Often the greater height of the first bean limits the number of internodes on which the beans are staked and developed. The positive influence on the total number of beans per plant is strong. It has been proven that the number of beans per internode also increases, contributing to an increase in their total number on the entire plant. The average number of seeds per pod does not change unidirectionally as a consequence of soil moisture optimization, but within the plant there may be corrective functions regarding the total number of seeds. Planting the maximum number of pods, under optimal irrigation, the plants set the maximum number of seeds in them, but only between 50 and 60% of them manage to fully develop. In rare cases, the share of fully developed seeds can reach up to 70%. Usually, the ratio between the different categories of seeds (fully developed, underdeveloped and missing) under an optimal irrigation regime is not the most favorable, but nevertheless in medium and moderately dry years its influence on the total number of fully developed seeds per plant is positive and strongly expressed. Absolute seed mass is not of primary importance in relation to yield, but it often has corrective functions, usually in a positive direction. The optimal irrigation regime does not guarantee maximum absolute seed mass. This also applies to their hectoliter mass. However, it guarantees a maximum yield for the specific conditions, consisting of fully developed seeds.

Irrigation during the period of bean formation: Irrigation given during this period (R3-R4) is most effective, as it performs a double function - it accelerates vegetative growth and creates conditions for the formation of a larger number of beans. Its influence on vegetative growth is usually medium and rarely weak or strong, being expressed through the increased number of internodes and the greater height of the plants, increasing their productive potential. This also affects the number of beans per plant, but the impact is strong only in years when this watering prevents significant soil drying during bean formation. With a more favorable combination between it and precipitations, its influence on the number of beans is weak or insignificant. Watering during this part of the vegetation may have a positive effect on the number of beans at the internodes, but there is no clear trend indicating the reason determining this effect. However, it can to some extent correct the total number of pods per plant - also in a positive direction. When this irrigation was given under conditions of mild water deficit and with a favorable combination of precipitations, it did not significantly change the number of seeds per plant, but when it was applied under conditions of moderate water deficit, its positive effect on the number of fully developed seeds is very pronounced, although it most often does not contribute to the improvement of the ratio between the categories of seeds (the relative share of fully developed seeds decreases). This is observed when it is followed by a significant and prolonged drought, covering the pod-filling period. This watering does not unidirectionally affect the average number of seeds per pod, although as a result of its implementation, it often increases. Its application in most cases does not change the absolute mass of the seeds. Nevertheless, it can significantly increase the yield, which is mainly due to the number of fully developed seeds. The effect of the irrigation given during the bean formation period increases significantly when it is combined with another irrigation. It is more appropriate to combine it with one watering during the period of pod-filling, thus greatly improving the parameters of the reproductive components, and the share of fully developed seeds reaches maximum values that vary in a relatively small range - between 60 and 70%. The yield is close to the maximum for the relevant conditions. When combined with one watering during flowering, the positive influence on the vegetative components increases significantly. Improvement of reproductive components is possible, but it is weaker.

Irrigation during the seeding period: This irrigation should usually compensate for a moderate to severe water deficit, since insufficient rainfall and the maximum of the mean diurnal ET result in significant drying of the active soil layer. Even with an optimal irrigation rate, this irrigation cannot really moisten the entire active soil layer, therefore it covers part of the root system and usually has a short-term positive effect. It practically does not affect the vegetative parameters, but depending on the conditions of the year, it can affect the reproductive ones. If carried out at the beginning of the R5 phase, it can have a positive effect on the number of fully developed seeds, and this effect is more often weak. Applied towards the middle of the phase, as well as towards its end, it favors the increase of the absolute mass of the seeds (also weakly), but if it is applied after a long and pronounced soil drought, the effect is rather the opposite, due to the remobilization of nutrients to the vegetative parts of the plant, in detriment of the beans and seeds in them. The positive influence of this watering is uncertain and depends very much on the conditions before pod-filling, as well as during which part of this phenophase it is applied. In middle years with more significant drought until the end of bean formation, the influence of irrigation on the yield is weak, and in more favorable conditions - absent. In mid-dry years with significant drought until the end of pod formation, the additional yield is substantial, but if irrigation is given at the end of R5 or later - in R6, the yield also does not increase. In combination with another watering, the watering during the pod-filling period increases its efficiency, and it is recommended to combine it with one watering during the bean formation period, if necessary, because in combination with one watering during flowering, the effect on the yield is less pronounced at the same irrigation costs.

Irrigation during the flowering period: This irrigation is the least effective in terms of development and yield in soybeans. The reason for this is that once it is depleted, plants can only rely on precipitations, and they are unreliable. For this reason, during the period of bean formation and pod-filling, a water deficit very often occurs, which increases significantly as the vegetation progresses. This watering affects the vegetative components, increasing the number of internodes of the plants, and with it the productive potential. In most cases, however, it cannot be fully implemented, due to the already mentioned reasons. Reproductive components are almost unchanged. The yield, as a result of this irrigation, increases little or not at all, and the low relative share of fully developed seeds (between 46

and 58%) contributes to this. As already noted, it can be combined with another watering, which will be during the period R3-R5, thus its effect is greater.

Irrigation with reduced irrigation rates: When reducing irrigation rates, the number of irrigations is not changed, thus allowing for a more complete use of precipitation, combined with significant or partial restoration of optimal soil moisture during each of the critical phenophases. Under these conditions, the increase in the amount of irrigation rates leads in parallel to the improvement of the parameters of the vegetative and reproductive components of the yield. Irrigation with very small irrigation rates (30%*m*) practically does not increase the yield, except in years with more substantial and relatively evenly distributed precipitations. The application of ½ rate is more effective, with a visible positive influence on almost all yield components. In this irrigation regime, the share of fully developed seeds is always higher than in the other variants irrigated with reduced irrigation rates, including the optimal and non-irrigated ones. Irrigation at ½ rate has a weak to medium and less often strong positive effect on yield, and in more meteorologically favorable years, the supply of irrigation water in each row is recommended. It, together with the precipitation, covers and relatively well moistens the 0-40 cm layer, while in dry years, this is impossible or is observed only after the first watering. In dry years or years with longer summer droughts, the implementation of the ½ norm is better done by supplying the water through the interrow. In this way, the soybean root system is better covered, considering that it has the ability to reorient itself in the direction of the moistened part of the active soil layer (to the moistened interrow). Irrigation at a rate of 70%*m* provides near-optimal conditions as the critical 0-40cm soil layer is always moistened. This has a positive effect on both vegetative and reproductive components of yield. Moderate to strong is the positive influence on the number of internodes per plant (including the central stem), which is reflected in an equivalent way on plant height. In middle years, but with a more favorable distribution of precipitations, the influence of this irrigation regime on the number of pods per plant is average, and in years with more substantial and prolonged suffocation, it is strong. This effect is transferred in parallel to the number of seeds per plant and, accordingly, the yield. Since under this irrigation regime the number of seeds per plant is large, the share of fully developed ones is slightly smaller (47-60%), and their absolute mass rarely exceeds that under non-irrigated conditions. Since the yield is mainly determined by the number of fully developed seeds, their lower share in the total number, as well as their smaller absolute mass, do not have a significant impact.

• ***Negative impact of the deficit irrigation regime - comparison with the results of optimal irrigation.***

Cancellation of 1 watering during the flowering period: It greatly affects the number of internodes on the central stem, thus the plants remain shorter. With less favorable branching development, the total number of internodes of the whole plant is moderately to strongly reduced, as a result of which the productive potential is also reduced. In the event that this watering is canceled at a soil moisture of 80% FC, conditions are not created for the assumption of a significant water deficit, since for the climatic conditions of our country, this canceled watering is usually the first in a row. The next irrigation is carried out at a soil moisture not lower than 70% FC, then by the end of the irrigation period, the soil moisture moves within favorable limits for soybeans. Under these conditions, the formation of the beans and the seeds in them proceeds optimally, as evidenced by the fact that between 66 and 68% of the planted seeds develop fully. The yield is similar to that - with optimal irrigation, except for the cases where the cancellation of this irrigation reduces more significantly the number of internodes and prevents the optimal flowering. Thus, the number of pods decreases more significantly and directly affects the yield, through the number of seeds. Thus, the high percentage of fully developed seeds cannot compensate for these losses and the yield decreases. The results show that, from a biological point of view, canceling one watering through flowering and giving all other necessary waterings does not compromise the yield of a plant, or if there is a yield loss, it is small.

Cancellation of 1 watering during the bean formation period: Cancellation of irrigation during the pod formation period ensures optimal soil moisture until the R3 or R4 stage, as well as during the R5-R6 pod-filling period. If the irrigations preceding this cancellation were carried out on time and with an optimal irrigation rate, the beginning of the drought period will start with a minimal deficit, which, due to the rapid increase in daily ET, very quickly turns into a moderate one. It is possible that in some soil layers the humidity can reach very low values in a short time. The main vegetative components are

moderately to strongly affected, and the number of internodes of the plants decreases most significantly. In years with extreme drought during this part of the vegetation, the rest of the vegetative components of the yield are also negatively affected, and the limited development of the branches is of more significant importance in this case. All this significantly lowers the productive potential of the plants developed under these conditions. As drought during this phenophase affects the pod formation process, the realization of this already limited productive potential is further compromised. The number of pods is greatly reduced, with direct consequences for yield. If during this period more substantial rainfall falls, which somewhat compensates for the created deficit, the negative influence on the number of beans decreases to medium and even to weak. With more significant amounts of rainfall, which moisten the soil to at least 40cm depth, the number of beans remains unaffected. Since there is a close relationship between the number of pods and the number of seeds (total set) per plant, the impact of drought during this period affects both indicators almost equally. How much the yield of a plant will be affected, the percentage of fully developed seeds relative to the total number of seeds is of great importance. When irrigation was canceled during this part of the soybean growing season, these values varied widely, confirming the water criticality of the phenophase. The results are conclusive that allowing drought during the period of pod formation has a more pronounced negative effect, compared to the consequences for soybean caused by canceling irrigation during flowering.

Cancellation of 1 irrigation during the pod-filling period: Although the results showed some negative impact on the vegetative components, the drought induced during the pod-filling period had a rather negative effect on some of the reproductive parameters. The number of fully developed seeds per plant, which forms the actual yield, is most affected. Absolute seed weight decreased more significantly when irrigation was canceled at the beginning of the R5 phase. If the irrigation cancellation is done later in this phase, the effect is weakened, and in R6 it is non-existent. Although the number of seeds per plant is primarily compromised under this irrigation regime, this may be sufficient to account for a weak to moderate impact, and in years with higher meteorological stress it may grow to a strong one. As a negative impact on development and yield in soybean, drought during the pod-filling period is inferior to that during the pod formation period, but is stronger than that during the flowering period.

Negative impact of reduced irrigation rates: Maintaining the number of waterings reduces the negative impact of water deficit, and to some extent this also applies to the smallest irrigation rates (30%*m*). The higher the rate, the less affected certain yield components are, but in general, reproductive components are more affected because they are formed at a later stage when the water deficit is greater, in contrast to the vegetative components, which finish their development earlier and suffer less. The damage caused to plants by irrigation with very small irrigation rates is comparable to that which occurs under non-irrigated conditions. The exception is years when the rainfall is relatively favorable in terms of quantity and distribution, and the small irrigation rates only supplement them. This happens rarely, and due to unsatisfactory results, this irrigation regime is not justified from a biological point of view and should not be applied in production conditions, even in acute irrigation water shortages. Reducing the irrigation rate by $\frac{1}{2}$ leads to a strongly pronounced negative effect on the number of pods per plant, and in years with a more favorable distribution of precipitation, this negative effect is average. With more significant rainfall during the period of bean formation, even if they are not completely sufficient, the number of beans is practically equal to that - with optimal irrigation, providing close to the maximum number of fully developed seeds. As noted above, with this irrigation regime, they reach the largest of the total number of existing ones. This in more favorable years can bring the yield as close as possible to that - under optimal irrigation, and in drier years, compensate for the loss of beans. However, this is not enough in terms of yield loss. During such years, it decreases significantly, and the negative influence is classified as strong. The reduction of irrigation rates by 30% cannot be considered insignificant, and as the results of the experiment show, it affects a large part of the yield components, but significantly less, compared to the previous two irrigation regimes. A reduction in the number of internodes was observed (weak to medium), and in terms of number of pods, this effect was medium to strong, except in years when precipitations during the period R3-R4 were more significant. Likewise, this irrigation regime also affects the number of developed seeds per plant, as the ratio between different categories of seeds is similar to that of optimal irrigation. Absolute seed weight does not decrease as a result of the deficit created, so the yield per plant is affected in exactly the same way as the number of fully developed seeds. In practice, in half of the experimental years, the negative impact of the 30%

reduction in irrigation rates was highly pronounced. This should be taken into account both in the conditions of real agriculture and when setting up similar field experiments with a scientific purpose.

Actual yield

The yield from a unit of area is directly related to the yield from one plant, which is why the analyzes made in the previous section are also valid for this indicator.

Table 8. Yield by variants and years

№	variant	% m	Y (kg/da)	to dry		to optimum		Y (kg/da)	to dry		to optimum	
				±kg/da	%	±kg/da	%		±kg/da	%	±kg/da	%
2003								2004				
1	0000	—	131	St.	100.0	-210 ^c	38.4	184	St.	100.0	-157 ^c	54.0
2	++++	100	341	+210 ^c	260.3	St.	100.0	341	+157 ^c	185.3	St.	100.0
3	0+++		312	+181 ^c	238.2	- 29 ^{n.s.}	91.5	274	+ 90 ^c	148.9	- 67 ^c	80.4
4	+0++		256	+125 ^c	195.4	- 85 ^c	75.1	231	+ 47 ^c	125.5	-110 ^c	67.7
5	++0+		295	+164 ^c	225.2	- 46 ^b	86.5	—	—	—	—	—
6	+++0		—	—	—	—	—	—	—	—	—	—
7	+000		185	+ 54 ^c	141.2	-156 ^c	54.3	231	+ 47 ^c	125.5	-110 ^c	67.7
8	0+00		228	+ 97 ^c	174.0	-113 ^c	66.9	274	+ 90 ^c	148.9	- 67 ^c	80.4
9	00+0		170	+ 39 ^a	129.8	-171 ^c	49.9	—	—	—	—	—
10	000+		—	—	—	—	—	—	—	—	—	—
11	++++	70	308	+177 ^c	235.1	- 33 ^a	90.3	308	+124 ^c	167.4	- 33 ^b	90.3
12	++++	50	279	+148 ^c	213.0	- 62 ^c	81.8	265	+ 81 ^c	144.0	- 76 ^c	77.7
13	++++	30	214	+ 83 ^c	163.4	-127 ^c	62.8	234	+ 50 ^c	127.2	-107 ^c	68.6
14	++++	50*	264	+133 ^c	201.5	- 77 ^c	77.4	237	+ 53 ^c	128.8	-104 ^c	69.5
		GD(kg/da): 5%=30, 1%=41, 0.1%=54						GD(kg/da): 5%=19, 1%=27, 0.1%=38				
2005								2006				
1	0000	—	196	St.	100.0	- 27 ^{n.s.}	87.9	215	St.	100.0	-147 ^c	59.4
2	++++	100	223	+27 ^{n.s.}	113.8	St.	100.0	362	+147 ^c	168.4	St.	100.0
3	0+++		—	—	—	—	—	337	+122 ^c	156.7	- 25 ^{n.s.}	93.1
4	+0++		—	—	—	—	—	273	+ 58 ^c	127.0	- 89 ^c	75.4
5	++0+		—	—	—	—	—	270	+ 55 ^c	125.6	- 92 ^c	74.6
6	+++0		—	—	—	—	—	—	—	—	—	—
7	+000		—	—	—	—	—	231	+ 16 ^{n.s.}	107.4	-131 ^c	63.8
8	0+00		—	—	—	—	—	236	+ 21 ^{n.s.}	109.8	-126 ^c	65.2
9	00+0		—	—	—	—	—	248	+ 33 ^a	115.3	-114 ^c	68.5
10	000+		—	—	—	—	—	—	—	—	—	—
11	++++	70	208	+12 ^{n.s.}	106.1	- 15 ^{n.s.}	93.3	322	+107 ^c	149.8	- 40 ^b	89.0
12	++++	50	237	+41 ^{n.s.}	120.9	14 ^{n.s.}	106.3	313	+ 98 ^c	145.6	- 49 ^c	86.5
13	++++	30	203	+ 7 ^{n.s.}	103.6	- 20 ^{n.s.}	91.0	245	+ 30 ^a	114.0	-117 ^c	67.7
14	++++	50*	237	+41 ^{n.s.}	120.9	+14 ^{n.s.}	106.3	312	+ 97 ^c	145.1	- 50 ^c	86.2
GD(kg/da): 5%=68, 1%=93, 0.1%=129								GD(kg/da): 5%=26, 1%=34, 0.1%=45				

Despite the small differences between the data for the yield of a single plant and the yield of the harvested plots, the correlation between the two sets of data (absolutely all available experimental values) is $R>0.8$. The yield data from the harvest plots by variants, years and average for the experimental period are presented in Table 8.

Table 8. Continued

№	variant	% m	Y (kg/da)	to dry		to optimum		Y (kg/da)	to dry		to optimum	
				±kg/da	%	±kg/da	%		±kg/da	%	±kg/da	%
		2007								2008		
1	0000	—	109	St.	100.0	-209 ^c	34.3	202	St.	100.0	-152 ^c	57.1
2	++++	100	318	+209 ^c	291.7	St.	100.0	354	+152 ^c	175.2	St.	100.0
3	0+++		288	+179 ^c	264.2	- 30 ^{n.s.}	90.6	306	+104 ^c	151.5	-48 ^c	86.4
4	+0++		267	+158 ^c	245.0	- 51 ^b	84.0	298	+ 96 ^c	147.5	-56 ^c	84.2
5	++0+		244	+135 ^c	223.9	- 74 ^c	76.7	329	+127 ^c	162.9	-25 ^a	92.9
6	+++0		—	—	—	—	—	—	—	—	—	—
7	+000		136	+27 ^{n.s.}	124.8	-182 ^c	42.8	220	+18 ^{n.s.}	108.9	-134 ^c	62.1
8	0+00		195	+86 ^c	178.9	-123 ^c	61.3	278	+76 ^c	137.6	-76 ^c	78.5
9	00+0		137	+28 ^{n.s.}	125.7	-181 ^c	43.1	278	+76 ^c	137.6	-76 ^c	78.5
10	000+		—	—	—	—	—	—	—	—	—	—
11	++++	70	256	+147 ^c	234.9	- 62 ^c	80.5	324	+122 ^c	160.4	-30 ^b	91.5
12	++++	50	227	+118 ^c	208.3	- 91 ^c	71.4	304	+102 ^c	150.5	-50 ^c	85.9
13	++++	30	182	+ 73 ^c	167.0	-136 ^c	57.2	264	+ 62 ^c	130.7	-90 ^c	74.6

14	++++	50*	225	+116 ^c	206.4	- 93 ^c	70.8	314	+112 ^c	155.4	-40 ^c	88.7
				GD(kg/da): 5%=32, 1%=43, 0.1%=56				GD(kg/da): 5%=20, 1%=27, 0.1%=35				
				2009				Average for the experimental period				
1	0000	–	104	St.	100.0	-125 ^c	45.4	163	St.	100.0	-147	52.6
2	++++	100	229	+125 ^c	220.2	– St.	100.0	310	+147	190.2	St.	100.0
3	0+++		208	+104 ^c	200.0	- 21 ^b	90.8	–	–	–	–	–
4	+0++		194	+ 90 ^c	186.5	- 35 ^c	84.7	–	–	–	–	–
5	++0+		173	+ 69 ^c	166.3	- 56 ^c	75.5	–	–	–	–	–
6	+++0		191	+ 87 ^c	183.7	- 38 ^c	83.4	–	–	–	–	–
7	+000		153	+ 49 ^c	147.1	- 76 ^c	66.8	–	–	–	–	–
8	0+00		163	+ 59 ^c	156.7	- 66 ^c	71.2	–	–	–	–	–
9	00+0		163	+ 59 ^c	156.7	- 66 ^c	71.2	–	–	–	–	–
10	000+		108	+ 4 ^{n.s.}	103.8	-121 ^c	47.2	–	–	–	–	–
11	++++	70	218	+114 ^c	209.6	- 11 ^{n.s.}	95.2	278	+115	170.6	- 32	89.7
12	++++	50	205	+101 ^c	197.1	- 24 ^c	89.5	261	+ 98	160.1	- 49	84.2
13	++++	30	189	+ 85 ^c	181.7	- 40 ^c	82.5	219	+ 56	134.4	- 91	70.6
14	++++	50*	208	+104 ^c	200.0	- 21 ^b	90.8	257	+ 94	157.7	- 53	82.9
				GD(kg/da): 5%=13, 1%=18, 0.1%=24								

Yield-Water relationship

The Yield-Irrigation rate relationship

This dependence is most correctly represented by the power formula proposed by D.Davidov. The variant is recommended, in which the additional yield is predicted based on data on the irrigation rate at R=0.964. For the conditions of this experiment (all trials with deficit irrigation regime), the equation has the following form: $Y=1 - (1 - m)^{1.40}$.

Relationship between yield and evapotranspiration

Table 9. Parameters of the relationship "Yield-annual ET" valid for the layer 0-100cm by years

linear Y=1-Kc(1-x)	R	power Y=1-a(1-x) ⁿ	R	two power Y=[1-(1-x) ⁿ] ^m	R
2003 Biser variety					
Y=1-1.50(1-x)	0.995	Y=1-3.18(1-x) ^{1.52}	0.851	Y=[1-(1-x) ^{1.97}] ^{7.51}	0.999
2004 Biser variety					
Y=1-2.15(1-x)	0.898	Y=1-3.08(1-x) ^{1.20}	0.874	Y=[1-(1-x) ^{1.45}] ^{6.23}	0.878
2006 Biser variety					
Y=1-1.23(1-x)	0.939	Y=1-2.99(1-x) ^{1.61}	0.970	Y=[1-(1-x) ^{2.01}] ^{6.24}	0.958
2007 Biser variety					
Y=1-1.75(1-x)	0.939	Y=1-2.09(1-x) ^{1.12}	0.954	Y=[1-(1-x) ^{1.47}] ^{4.32}	0.929
2008 Srebrina variety					
Y=1-1.35(1-x)	0.963	Y=1-2.90(1-x) ^{1.50}	0.990	Y=[1-(1-x) ^{1.46}] ^{3.15}	0.985
2009 Srebrina variety					
Y=1-1.19(1-x)	0.699	Y=1-38.4(1-x) ^{3.76}	0.987	Y=[1-(1-x) ^{4.76}] ¹⁶⁷	0.986
2004 Mira variety					
Y=1-2.03(1-x)	0.904	Y=1-3.10(1-x) ^{1.27}	0.894	Y=[1-(1-x) ^{1.47}] ^{5.57}	0.892
2006 Mira variety					
Y=1-1.42(1-x)	0.944	Y=1-2.2(1-x) ^{1.31}	0.945	Y=[1-(1-x) ^{1.59}] ^{3.91}	0.914

The Yield-annual ET relationship: The parameters of the relationship "Yield-annual ET" are presented in table 9 and in fig. 25. The three variants of the relationship demonstrate very high and approximately equal accuracy. This is due to the fact that in the zone of real yield, where the main part of the empirical points is concentrated, the graphs are located close to each other. If the whole range of the relationship is considered, preference should be given to the two-power formula, since it reflects more smoothly the change in yield, depending on the total ET. Very close to it is the power formula, and finally – the linear formula of FAO.

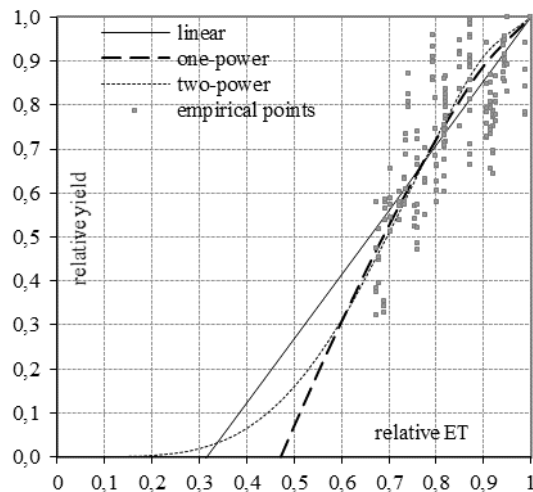


Fig.25. Relationship „Yield-annual ET”

Relationship between yield and ET by phenophases (periods)

This variant of the relationship was studied for the conditions of the conducted experiments, and the two-power formula proposed by D.Davidov demonstrated the highest accuracy and precision. It shows the sensitivity of the phenophases in the R1-R6 range. The remaining formulas also show high mathematical accuracy ($R > 0.9$), with some differences regarding the sensitivity of the phenophases. Regardless of the formula used, however, this type of relationship cannot correctly represent and quantify the real sensitivity of the different phenophases. This is due to the fact that at the same time there are at least two main phenophases, each of which is specific in terms of water requirements. In addition, the relationship is investigated on the basis of data obtained during regular irrigation with different irrigation rates, i.e. no water deficit is actually allowed during a particular phenophase. For the correct consideration of the sensitivity of individual phenophases, the water deficit accumulated over time in the active soil layer has an impact. This means that it increases during each subsequent phenophase, and at the same time the differences between variants with different irrigation rates also increase. Thus, it turns out that each subsequent phenophase has a greater sensitivity than the previous one, and this is not always the case. This shortcoming is not just about soybeans as a crop, but rather how the parameters of this relationship are determined, regardless of the crop.

INFLUENCE OF THE IRRIGATION REGIME ON COMPONENTS OF THE CHEMICAL COMPOSITION OF SOYBEAN SEED

Under irrigation with reduced irrigation rates: The crude protein content of soybean seeds is more strongly influenced by the conditions of the year, being between 41 and 42% in warmer and drier years. In cool and wet years, the values fall to 35-38%. Irrigation with different irrigation rates does not affect this indicator unidirectionally. For the conditions of the experiment, the content of crude fat is within limits typical for soybeans (20-23%), and the amount of the irrigation rate does not change it significantly and unidirectionally, regardless of the conditions of the year. Using the experimental data, an inverse square relationship between crude protein and crude fat content was found at $R = 0.66$. Irrigation with different irrigation rates does not significantly affect the content of nitrogen-free extractives, crude fiber and crude ash. There is a tendency for lysine to decrease with increasing irrigation rates. The data on the content of the investigated chemical components, depending on the irrigation rate, are presented in Fig. 26.

The highest IWUE is observed with irrigation at a rate of 50%, which is due to the specificity of the "Irrigation rate-yield" relationship. WUE is highest under irrigation with rates in the 70-100% range. There is a close linear relationship between seed WUE and that of crude fat and crude protein at $R \geq 0.98$. This dependence regarding IWUE is also very well expressed at $R \geq 0.95$.

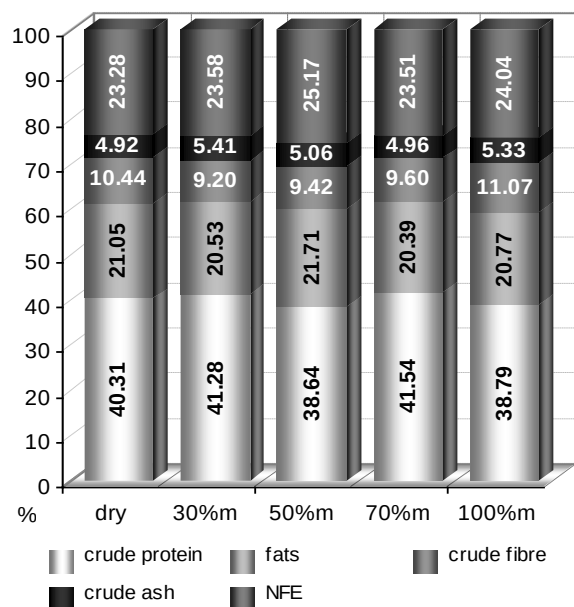


Fig.26. Relative distribution of chemical components in soybean seeds as a function of the amount of irrigation rates

The relationship between the CP yield and the irrigation rate is power ($n=1.44$) with $R=0.96$. Regarding crude fat, the relationship is also power with $n=1.26$ and $R=0.95$. The relationship between CP yield and ET is a two-power function ($n=1.87$, $m=6.05$ and $R=0.96$). Regarding CF, it is also two-power with the following parameters: $n=1.62$, $m=4.9$ and $R=0.95$. It is represented graphically by means of an S-shaped curve. The results of this experiment give reason to consider that increasing the yield of the valuable components (protein and fat) in soybeans should be achieved by increasing the seed yield, by applying an appropriate irrigation regime, and not by looking for an option to increase their content in seeds. An increase in the amount of irrigation rates is guaranteed to increase the yield of these two components.

Irrigation canceling by phenophases: Canceling irrigations during the pod-filling period (R5 and R6) leads to the most significant decrease in crude protein content, with the conditions of the year having an additional influence. The drier the year, the lower the values. Cancellation of 1 irrigation during the pod formation period had little or no negative effect on soybean seed protein content, which somewhat compensated for the more significant losses in seed yield. As well as reducing the seed yield, the cancellation of irrigation during the reproductive period also leads to a decrease in the yield of crude protein. This influence is more pronounced in drier years. Losses are in the 15-20% range, but in more extreme droughts during the pod-filling period, they can exceed 30%.

With regard to crude fats, the cancellation of irrigation during the period of pod-filling (R5-R6) has the most favorable effect, which increases their content compared to all other irrigation regimes of this group, including the non-irrigated and optimally irrigated variants. The drier the year, the greater the differences. Cancellation of watering during flowering (R2) does not change the content of crude fat, compared to those - with optimal irrigation, and its change as a result of cancellation of watering during bean formation (R3-R4) is weak and unidirectional. Crude fat yield per unit area varies in parallel with seed yield. This confirms the opinion that it should be increased through the yield of seeds, and not by searching for ways to increase their content in seeds.

Canceling watering during the period of pod-filling leads to a more significant decrease in the content of lysine in them. This is due to a change in the metabolism of the plant. This effect is also enhanced in years with very pronounced drought during the reproductive period and especially during the phenophase of pod-filling.

Irrespective of which phenophase an irrigation was withdrawn, carrying out the remaining two or three irrigations increased the carbohydrate content of soybean seeds compared to that under non-irrigated conditions. It is more pronounced in dry years. Canceling irrigation during the pod-filling period significantly increases carbohydrate content. This is due to a change in the direction of movement of assimilates in the plant, in which the lowering of soil moisture to certain levels makes it possible to reach a maximum of its content in the yield.

Single irrigations: Crude protein content was highest in single irrigations only during flowering, due to the subsequent significant water deficit, including during the R5-R6 phenophases. Watering applied only during the period of bean formation mitigates the drought conditions during R5-R6, as a result of which the protein content decreases. Irrigation carried out as the only one during R5-R6 has a direct impact on the crude protein content, reducing it to levels comparable to those under optimal irrigation. This means that the degree of water availability of soybeans during the seeding period is decisive for their crude protein content.

Single waterings have little effect on the crude fat content of soybean seeds. Compared to the non-irrigated variant, watering during flowering increases it by between 0.3 and 0.7%. A single irrigation during pod formation (R3-R4) is ineffective in very dry years. It is weakly effective in medium dry years, and its effect increases in more favorable years, increasing the fat content by about 1%. The irrigation during the pod-filling period has a positive effect on fat content, but only in drier years. This phenophase is decisive, with the level of plant water availability influencing the values. Due to the absence of a significant and long-lasting water deficit until the beginning of pod-filling, irrigation during phase R5 or R6 does not give a positive effect.

Watering during bean formation provides 64-68% of the maximum fat yield. The values by year for the other two phenophases are close, which indicates approximately the same efficiency in terms of this indicator. The single irrigation during R5-R6 does not completely restore the optimal soil moisture, but only partially and thus creates the necessary conditions for the synthesis of the maximum amount of carbohydrates in the soybean seeds (up to 24.7-25.8%). Single waterings during the earlier phenophases provide a high content of nitrogen-free extractives, but compared to the indicated values, it is lower (from 1 to over 4%), especially for watering during the period R3-R4. The reason is that, in addition to strong vegetative growth, through it the plants must ensure the formation and development of the maximum number of beans.

IRRIGATION OF SOYBEANS AT HIGH PRE-IRRIGATION SOIL MOISTURE

Maintaining higher soil moisture (over 90%FC) is associated with giving a greater number of waterings (6-7), but with smaller annual irrigation rates. Their size represents from 22 to 53% compared to the norms at 80%FC. The irrigation period in this irrigation regime is longer, due to the fact that it starts about ten days earlier, and the inter-irrigation period is significantly shorter. The first four waterings are during the II period, and the remaining 3-4 waterings - during the III period.

Evapotranspiration: Irrigation at pre-irrigation soil moisture of 80%FC increases water consumption by an average of 50%. Irrigation at 90%FC further increases ET by between 5 and 13%, reaching values of 434 – 451mm. The application of such an irrigation regime practically does not change the relative distribution of ET by periods. The maximum of the daily values increases insignificantly (6.3mm per day) and is in the second decade of July, and the values above 6mm remain for about 2 decades (from July 1 to July 20). Regarding the layer-by-layer formation of ET, there are no differences between the two values of pre-irrigation soil moisture, as 91-92% of the annual ET established for 0-100cm is formed in 0-60cm. For the conditions of this experiment, the irrigation rate provides more than 50%, precipitation provides about 1/3 of the annual ET, and the initial water reserve occupies an average of 13%. The differences between the two values of pre-irrigation soil moisture are minimal (about 2%) and have no practical significance.

Productivity: Data on yield and its structural components give reason to consider that maintaining high pre-irrigation moisture (above 90%RH) for soybeans is unjustified from a biological point of view, since the increase in the productive potential of the plants is not realized in reality. i.e. there is no guarantee that the yield will be higher and of better quality. Considering that the irrigation in these cases is more intensive, the desired economic effect is also not guaranteed.

ECONOMIC INDICATORS

The economic efficiency of growing soybeans under conditions of different water supply and irrigation methods was determined for all experimental years. The parameters of the main economic indicators have been established. The costs are based on the actual agro-technical activities carried out, which are consistent with the soybean cultivation technology. The prices of all activities carried out and agrochemicals applied are current for the first half of 2022, and official sources were used for this purpose. Only on-site activities (excluding transport costs, etc.) are included, as only these can be relatively permanent. The results are presented here only in terms of two main indicators - production costs and net income.

Production costs

Production costs depending on the size of the irrigation rates

During the years with three irrigations, the production costs are close, with optimal irrigation they are in the range of 210-220 BGN/da, and with two irrigations, they are below 200 BGN/da. The reduction of irrigation rates leads to a gradual reduction of production costs, but it is not proportional to

the degree of their reduction. Compared to non-irrigated soybeans, production costs at the 30% irrigation rate increased by an average of 9%, and at the 50% rate, they were 14% higher.

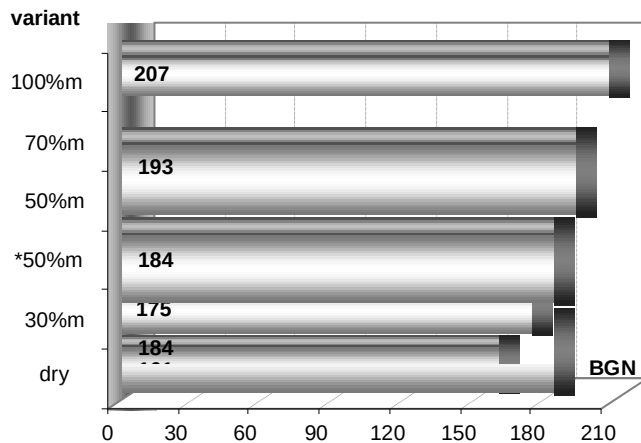


Fig.27. Average data on production costs depending on the size of the irrigation rate

Irrigation with higher irrigation rates increases costs on average by 20 and 29%, respectively for 70 and 100%*m*. Production costs in non-irrigated areas represent on average 78% of those in optimal irrigation, rising to 84% in irrigation with small irrigation rates (30%*m*). When irrigating with rates in the 50-70%*m* range, costs are between 89 and 93% of maximum. The data on the average production costs, depending on the irrigation rate, are presented in Fig. 27.

Production costs when canceling irrigation by phenophases

When a periodic water deficit is imposed, the values of this indicator depend to a greater extent on the total number of irrigations. For example, when canceling one out of two irrigations, the costs amount to about BGN 180/da. For example, when canceling one out of two irrigations, the costs amount to about BGN 180/da. If one out of three irrigations is cancelled, they are in the range of BGN 190-200/da, and in the case of 4 waterings, they exceed BGN 210/da.

The averaged values are presented in Fig.28. The maximum average difference does not reach 10 BGN/da, which makes predictable the costs valid for the agro-technics applied in the experiment. Due to the fact that with the Mira variety, waterings are two per growing season and are during the same phenophases, there is no difference in costs.

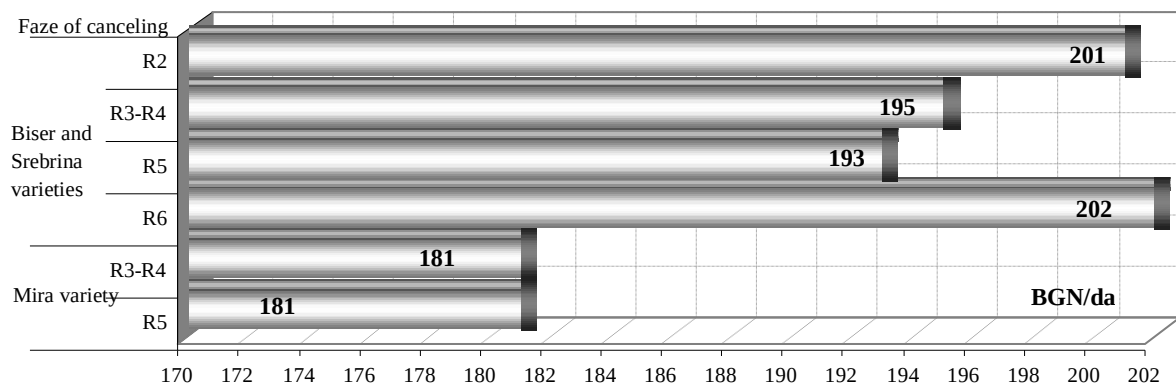


Fig.28. Average production costs when canceling one watering

Production costs for a single irrigation

Here there is always only one watering. Therefore, the costs are slightly lower. They do not depend on the conditions of the year and the total number of irrigations required for optimal irrigation, but to a certain extent only on the amount of the supplied irrigation rate. The range of variation by variants and years does not exceed 6BGN/da and is between 176BGN and 182BGN/da, i.e. with this agro-technological arrangement, the costs of growing soybeans with a single irrigation included are also predictable. The average production costs for a single irrigation are presented in Fig. 29. The slightly higher values for the Mira variety are due to the higher irrigation rates, according to the methodology of this experiment.

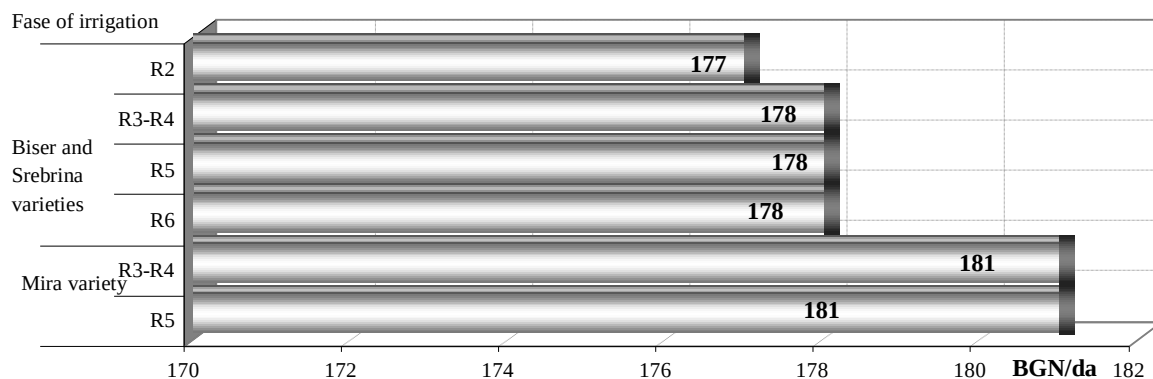


Fig.29. Average production costs for a single irrigation

Production costs depending on the pre-irrigation soil moisture

In general, costs change in proportion to changes in the level of pre-irrigation soil moisture in the range of 80-90%FC. This means that in order to have the same economic effect, the yield at the higher humidity must increase by a minimum of 10% compared to that at 80%FC.

Net income

Net income depending on the amount of irrigation rates

In almost all cases, the biologically optimal irrigation regime based on a pre-irrigation soil moisture of 80%FC for the 0-60cm layer is best from an economic point of view, since when irrigation rates are reduced, the net income decreases. The fact that the largest of the reduced irrigation rates (70%*m*) is economically inferior to the biologically optimal irrigation rate is probably due to the fact that the difference of 30% between the two irrigation rates is too large. However, the difference in net income between the two irrigation regimes is the smallest. It is greater between the norm 70 and 50%*m* and even greater – between the norms 50 and 30%*m*, reaching maximum values between the norm 30% and the non-irrigated version. This means that the change in net income depending on the size of the irrigation rates follows the trends valid for the relationship "Yield-irrigation rate".

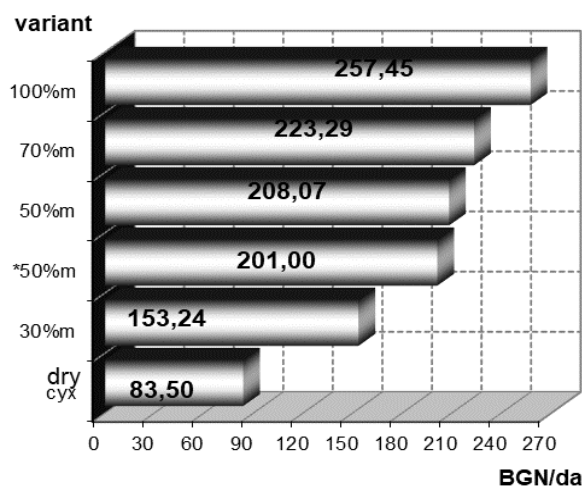


fig.30. Average production costs depending on the irrigation rate

Figure 30 shows the averaged data for the net income by variants, for the two experiments. The increasing difference in the values with each subsequent reduction in the irrigation rate is clearly visible. For example, between the optimal variant and an irrigation rate of 70%, it is on average 34BGN/da, between the rates of 50 and 30%, it increases to 55BGN/da, reaching 70BGN/da between the rate of 30% and the non-irrigated variant.

Net income in case of periodic water deficit by canceling irrigation

Since the cancellation of one irrigation does not result in significant changes in production costs, the impact on net income may be due to differences in yield. According to the results of the calculations, the cancellation of one irrigation during any part of the reproductive period of the soybean cannot provide a higher net income than that - with optimal irrigation. The best results are obtained when

watering is canceled during flowering, but before the beginning of pod formation, i.e. the period R1-R2. The net income under this irrigation regime is between 83 and 91% of the maximum. On average for 4 years, it is 217BGN/da, representing 87% of the maximum. Canceling irrigation during the period of pod formation and seeding worsens economic parameters, further reducing net income. In general, the cancellation of irrigation during the seeding period has a more pronounced negative impact on this indicator, although in some of the years, the cancellation of irrigation during the R3-R4 period generates a lower yield. This means that this entire period is risky, and the cancellation of irrigation during any part of it can lead to a significant deterioration of economic results, i.e. it is not recommended to allow a water deficit during the period R3-R6.

Net income with a single irrigation

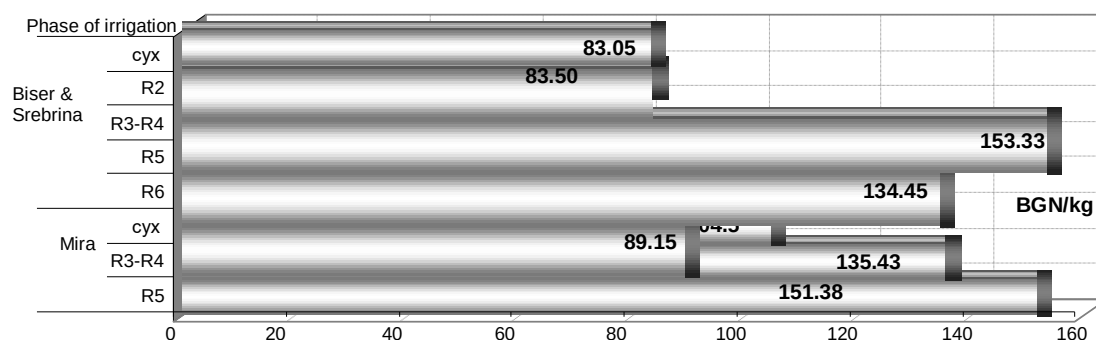


fig.31. Average net income for a single irrigation

The net income without irrigation depends on the meteorological conditions of the year, as they directly affect the yield. It is in the range of 130-160 BGN/da. Fig. 31 shows the average values of the net income for a single irrigation during different phenophases. A clearly expressed and strong positive effect of watering during the period of pod formation and pod-filling is observed, with the advantage being those during R3-R4. It can be considered that, from an economic point of view, irrigation during flowering (R2) and that carried out towards the end of the R6 phase are inefficient.

Net income depending on pre-irrigation soil moisture

On average for the two experimental years, the net income is 4BGN/da higher when maintaining 90%PPV, but if we look at the data by year, it surpasses the optimal irrigation regime only in the second year (2010), i.e. the positive financial effect of maintaining high soil moisture is not guaranteed (table 10).

Table 10. Net income depending on the value of pre-irrigation soil moisture

variant	measure	year		
		2009	2010	average
Without irrigation	BGN/da	-5.00	133.00	64.00
Drip irrigation at 80%FC		61.08	149.76	105.42
Drip irrigation at 90%FC		45.94	173.40	109.67

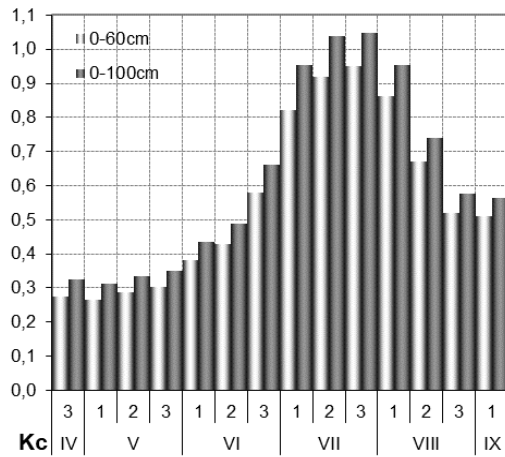
SOYBEAN IRRIGATION FORECASTING

Forecasting the timing of watering for soybeans based on indirect calculation of ET by the bio-climatic method

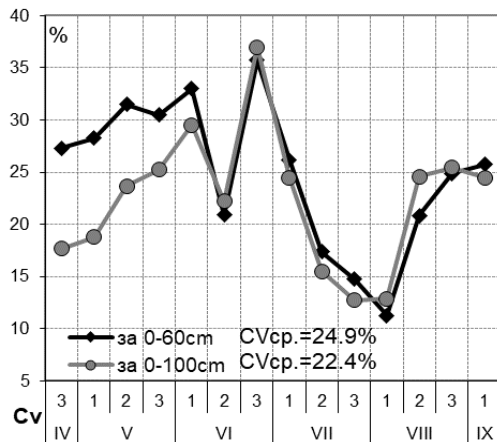
Of all the biophysical coefficients studied in the present work, the best results in terms of accuracy are shown by the FAO method and the temperature sum method. Therefore, the results are presented here and only these two coefficients are analyzed.

Summary results for the coefficient Kc.

The summarized data on the dynamics of the coefficient by decades are presented in Fig. 32. All results are averaged by years, experiments, techniques and varieties. Considering the relatively constant and very correct results presented above, it can be reasonably assumed that the values presented here are credible and reliable, regarding their application under real conditions.

(A) *Kc* by decades (average for all years and experiments)

month	decade	<i>Kc</i>	
		0-60cm	0-100cm
April	III	0.275	0.326
May	I	0.265	0.314
	II	0.287	0.335
	III	0.303	0.351
June	I	0.381	0.435
	II	0.428	0.489
	III	0.581	0.660
July	I	0.822	0.953
	II	0.920	1.037
	III	0.950	1.049
August	I	0.863	0.955
	II	0.670	0.740
	III	0.519	0.575
September	I	0.509	0.565

(B) *Cv* by decades (average for all years and experiments)

month	decade	<i>Cv</i> %	
		0-60cm	0-100cm
April	III	27.3	17.7
May	I	28.3	18.8
	II	31.5	23.7
	III	30.5	25.2
June	I	33.0	29.5
	II	20.9	22.2
	III	35.7	37.0
July	I	26.2	24.5
	II	17.4	15.5
	III	14.8	12.7
August	I	11.3	12.9
	II	20.8	24.6
	III	24.9	25.4
September	I	25.7	24.5

fig.32. Summarized ten-day values of the *Kc* coefficient

Averaged over decades, *Kc* increases smoothly, and initially (until the end of May) the increase is very slow. During the first two decades of June, it becomes more intense, after which the coefficient increases its values very quickly, reaching a maximum in the second and third ten days of July. Practically, for a period of about 1 month (from the second decade of July to the first decade of August /inclusive/), *Kc* is around the maximum, with values for the 0-60cm layer close to 0.9. During this period, on average for the 0-100cm layer they are close to 1.0. Calendar-wise, this part of the growing season usually coincides with phases R3-R4 and part of R5. After the first decade of August, *Kc* begins to decrease rapidly, but at the same time smoothly, reaching values of around 0.5 during the last two decades of the growing season. In addition to visual representation (on graph A), the average ten-day values of the coefficient are presented in a table accompanying the graph. They are final and may be used for predictive purposes. Graph B presents the *Cv* data by decade. The tendency for the weakest variation during the period between the second decade of July and the first decade of August (inclusive) is preserved, but compared to the other coefficients, here it is several times less, even in the decades with more substantial variation. The average values of *Cv* (for all ten days) are below 25%. The decadal variation of *Kc*, expressed as *Cv*, is presented in the accompanying table to graph B. Among the ten days mentioned above, the lowest variation is the first of August ($Cv=11\div15\%$).

Fig. 33 presents the summary results for *Kc* by phenophases. It increases gradually with a step of about 0.3 from the vegetative period to flowering, reaching a maximum during the pod formation phase, when for the layer 0-60cm $Kc\approx1.0$, and for the layer 0-100cm $Kc=1.1$, i.e. it can be assumed that during this part of the vegetation, the real ET and the reference ET practically coincide. This would further facilitate the procedures related to forecasting irrigation during this phenophase. During the pod-filling period, *Kc* decreases but remains still close to 1, then during the maturing period, due to the still high reference ET and the rapidly decreasing real ET, *Kc* decreases its values significantly. The minimal

variation during the phenophases of bean formation and pod-filling is confirmed, although during the rest of the soybean vegetation, it is significantly weaker compared to this - for the other coefficients. In general, the variation in the 0-100cm layer is weaker compared to that for 0-60cm, and the difference is more pronounced for Cv by phenophases, compared to Cv by ten days.

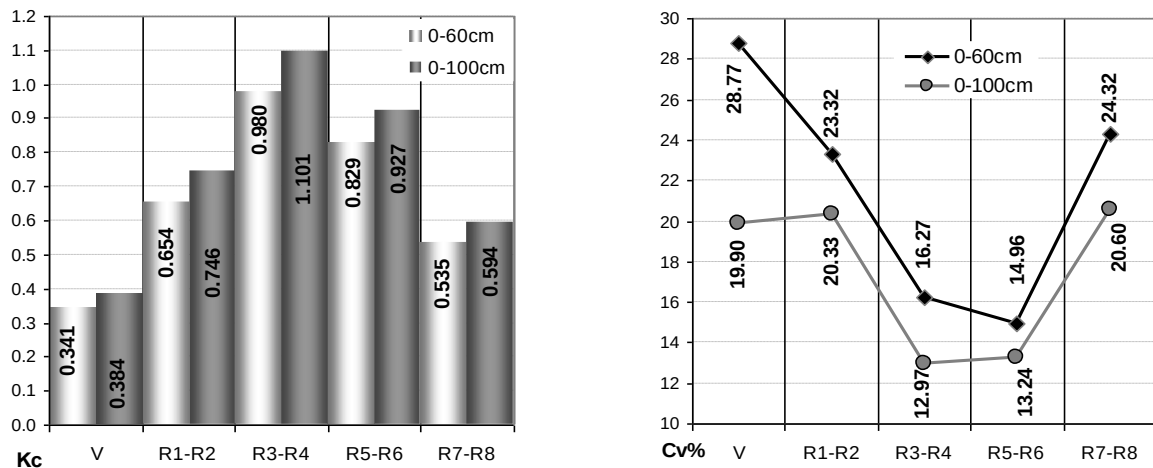
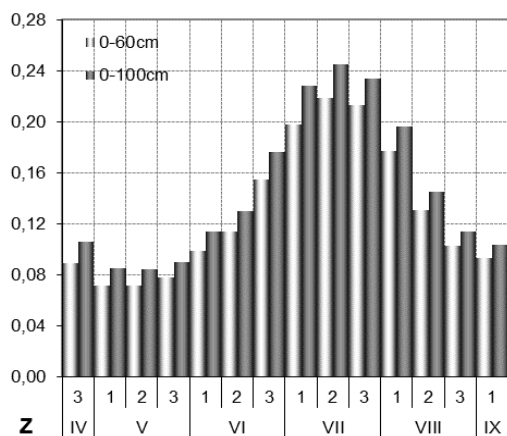


fig.33. Summary of Kc coefficient data by phenophases

Summary results for the Z coefficient

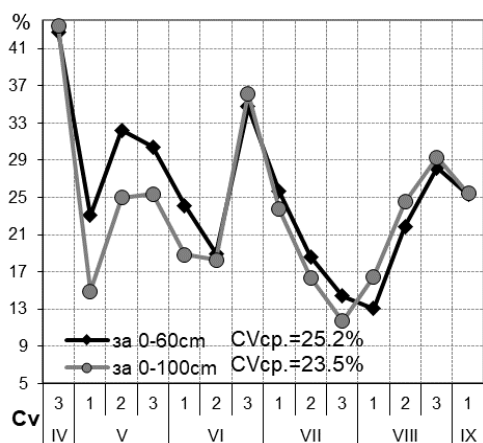
On average over decades, Z increases smoothly, and initially (until the end of May) it changes very slowly (Fig. 34). After the beginning of June, its values begin to increase more and more intensively, reaching a maximum in the second and third ten days of July. Practically, for a period of about 1 month (July), Z is around the maximum, with values between 0.20 and 0.22, which are valid for the 0-60cm layer. The maximum for the one-meter layer is at the same time, but with higher values ($Z=0.23\div0.24$). Calendar-wise, this part of the growing season usually coincides with phases R3-R4 and part of R2 or R5. In the first decade of August Z is still high. After that, it starts to decrease rapidly, but at the same time smoothly, reaching values of about 0.1 during the last two decades of the growing season. In addition to visual representation (on graph A), the exact ten-day values of the coefficient are presented in a table accompanying the graph. They are final and may be used for predictive purposes. Graph B presents the Cv data by decade. The tendency for the weakest variation during the period between the second decade of July and the first decade of August (inclusive) is preserved, but compared to the other coefficients, here it is several times less, even during the ten-day periods with more substantial variation. The increased stability of values during the first two decades of June can also be added here. The average Cv values (for all ten days) are around and below 25%. The decadal variation of Z expressed as Cv is presented in the companion table to Graph B. During the decades with the weakest variation noted above, Cv is below 20%, with the results for the 0-100cm layer being better. If we compare the results obtained by the last two methods, it becomes clear that the one-factor method of the temperature sum is in no way inferior in accuracy to the FAO method, which requires very large volume and usually expensive information, the processing of which requires additional resources, time and specialized computer programs. Therefore, for practical purposes the use of Z over Kc can be confidently recommended. This recommendation applies to the decadal average values of the coefficient.

(A) **Z** by decades (average for all years and experiments)



month	decade	Z	
		0-60cm	0-100cm
April	III	0.089	0.106
May	I	0.071	0.085
	II	0.072	0.084
	III	0.078	0.090
June	I	0.099	0.114
	II	0.114	0.130
	III	0.155	0.177
July	I	0.198	0.228
	II	0.218	0.245
	III	0.213	0.234
August	I	0.177	0.197
	II	0.131	0.145
	III	0.103	0.114
September	I	0.093	0.104

(B) Cv by decades (average for all years and experiments)



month	decade	Cv%	
		0-60cm	0-100cm
April	III	42.8	43.4
May	I	23.1	14.9
	II	32.2	24.9
	III	30.4	25.4
June	I	24.1	18.8
	II	18.9	18.3
	III	34.8	36.1
July	I	25.6	23.7
	II	18.6	16.4
	III	14.4	11.7
August	I	13.0	16.5
	II	21.9	24.5
	III	28.2	29.3
September	I	25.3	25.4

fig.34 Summarized ten-day values of the Z coefficient

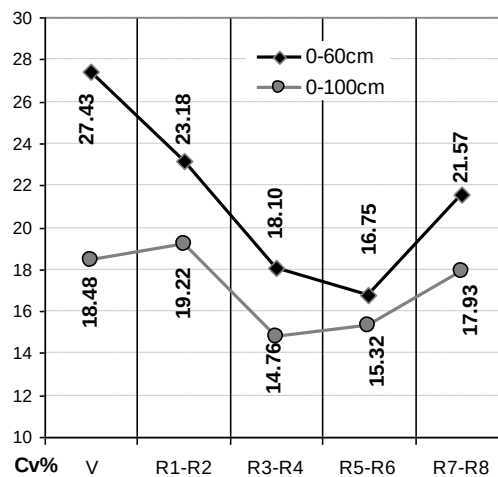
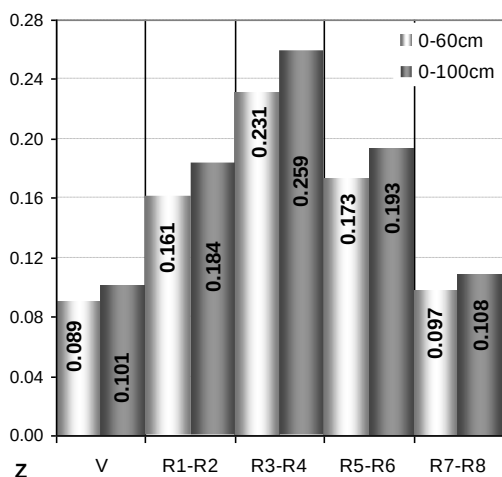


fig.35. Summary of Z coefficient data by phenophases

Fig. 35 presents the summary results for Z by phenophases. It increases gradually, with the step between the vegetative period and flowering exceeding, but not significantly, that between flowering and pod formation. The maximum is during the period of pod formation, and the values are within the limits characteristic of the culture. During the pod-filling period, Z decreases, but remains slightly higher, compared to flowering. Then, during the maturing period, due to the still high air temperature and at the same time the rapidly decreasing real ET, Z lowers its values significantly. The minimal variation during the phenophases of pod formation and pod-filling is confirmed, although during the rest of the soybean vegetation, it is significantly weaker compared to this - for the other coefficients. In general, the variation in the 0-100cm layer is weaker compared to that for 0-60cm, and the difference is more pronounced for Cv by phenophases, compared to Cv by ten days. Here again, the temperature sum

method is not inferior in accuracy to the FAO method, which is why it is recommended over all other methods, including in preference to the FAO method.

Leaf temperature as an indicator of plant water availability and a method for predicting watering in soybeans. The measurement of the temperature of the surface of the leaves is a remote indirect method for establishing the degree of water availability of plants, including those of soybeans. During the period of the experiments included in the development, numerous measurements were made in accordance with the accepted methodology, using an infrared thermometer (IR). The reason for conducting this study is the fact that when soil moisture decreases, water flow through plants decreases, as a result of which the intensity of transpiration also decreases. This makes it difficult to cool the leaves, i.e. other things being equal, the leaves of plants growing at lower soil moisture have a higher temperature than those with better water supply. The increased temperature can be unfavorable for the course of a large part of the biochemical and physiological processes in the plant organism. The graph in Fig.36 proves conclusively that the more favorable the soil moisture, the lower the measured leaf temperature. The difference between non-irrigated and optimally irrigated soybeans is clearly expressed, and the values for plants irrigated with reduced rates occupy an intermediate position.

Refinement of the infrared method for soybean irrigation prediction requires a very large number of observations and measurements, as leaf temperature is also affected by other factors. So, for example, when shaded by a cloud (no matter how small it is), the temperature drops instantly. Wind also affects, and when plants do not completely cover the soil surface, the heated soil has a positive effect on leaf temperature. It is likely that leaf age also affects dT° values. All other things being equal, varying air temperature changes dT° even though the soil moisture may be the same, i.e. there is a complex of side effects acting simultaneously with the soil moisture factor. The method of distributing the irrigation water between the rows when irrigating soybeans with a rate of 50% does not have a significant and one-way effect on the temperature of the leaves in soybeans (Fig. 37).

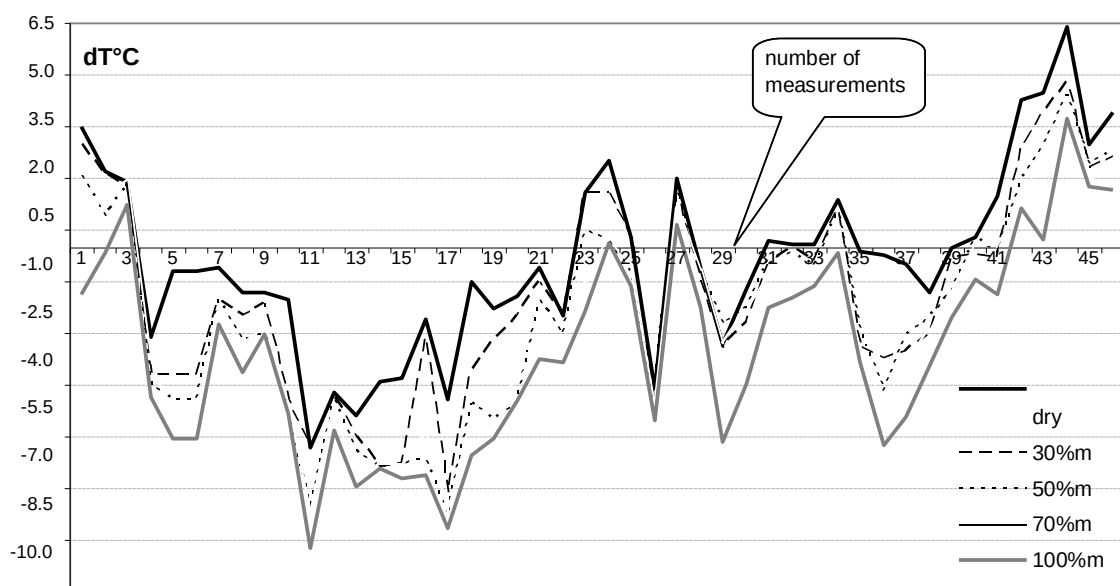


fig.36. Values of dT° depending on the irrigation regime

Irrigation technique has a slightly more significant influence on leaf temperature, and this influence is not constant and is usually tied to time, representing a few days immediately after irrigation. Sprinkler irrigation in most cases succeeds in further lowering the temperature of the leaves, compared to gravity and drip irrigation, by cooling them and, in addition, changing the short-term microclimate within the crop. The effect of the created water layer in the furrows and the subsequent moistening of the absolutely entire soil surface has a similar effect, but it is less pronounced. The least pronounced "oasis" effect is observed with drip irrigation, which is why the temperature of the leaves is slightly higher with it, compared to that with the other two techniques (fig. 38). Compared to the irrigation regime, however, the influence of the irrigation method is much weaker and short-term.

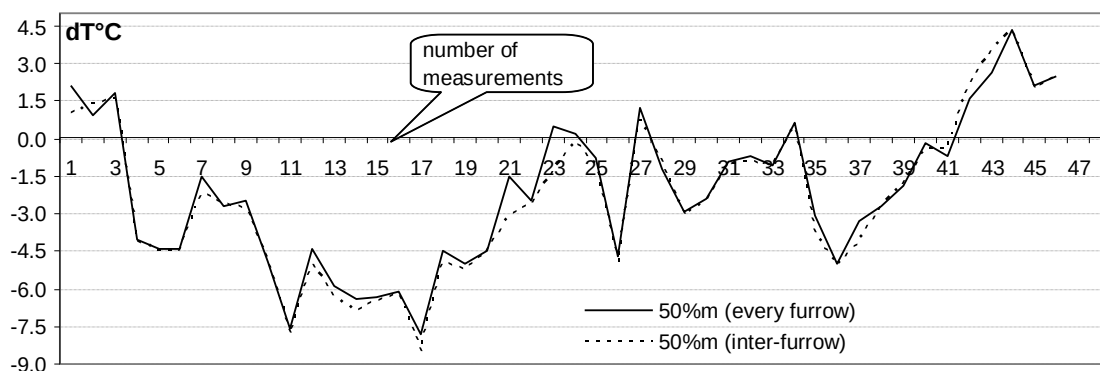


fig. 37. Values of dT° depending on the irrigation water distribution method

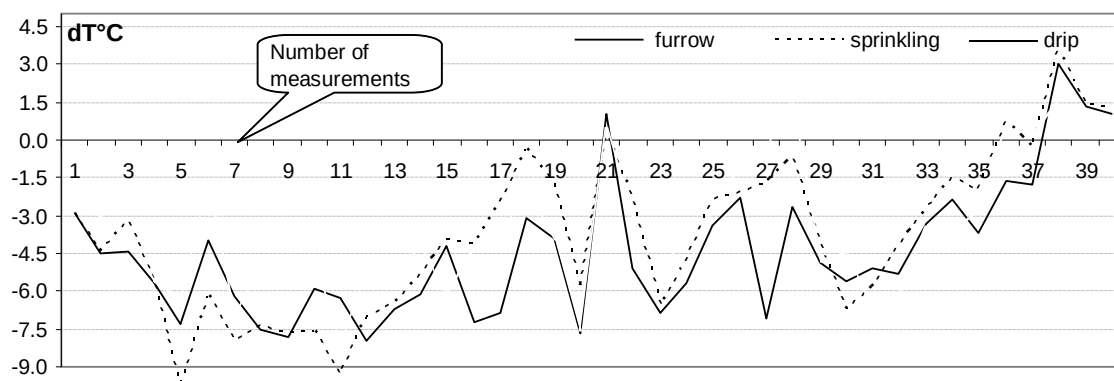


fig.38. Values of dT° depending on irrigation method

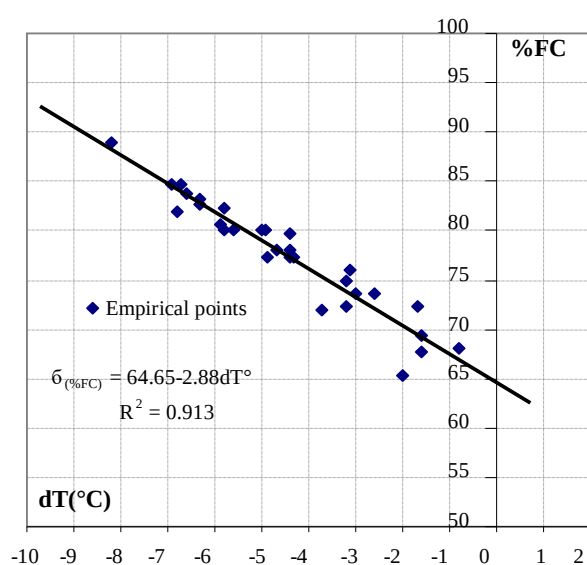


fig.40. Relationship between dT° and soil moisture (%FC)

Another indirect proof that it is not justified for the pre-irrigation soil moisture to be above 80%FC are the results presented graphically in Fig.39. The values of dT° at 90%FC are not greater (with a minus sign) than those - at 80%FC, i.e. frequent watering and higher soil moisture do not have a significant and one-way effect on soybean leaf temperature.

From the presented four graphs, it is clear that the temperature of the soybean leaves (specifically the Srebrina variety) rarely reaches the air temperature. The reason for this is the good ability of soybeans to supply water at lower levels of soil moisture. This leads to a weaker limitation of transpiration and, accordingly, better cooling of the leaves.

In order to clarify the influence of soil moisture on dT° values, a relationship between them was sought and established, using data from parallel measurements (of soil moisture and dT°) made at a given point at the same time. The relationship presented in Fig. 40 is valid for the soil layer 0-60 cm. It is linear at $R^2=0.913$.

The graph confirms the above statement, according to which the air temperature (T°_a) and the leaf temperature (T°_c) are equalized only when the soil moisture reaches 65%FC, i.e. at this soil moisture, $dT^\circ=0$, and when it falls below 65% RH, $dT^\circ>0$. For garden beans, for example, $dT^\circ=0$ when

the soil moisture is around 80%FC, i.e. it is necessary to carry out such studies separately for each agricultural crop.

Table 11. Prediction of pre-irrigation soil moisture in the 0-60cm layer based on dT° data

%FC	dT°	%FC	dT°	%FC	dT°	%FC	dT°	%FC	dT°	%FC	dT°
51.7	4.5	60.3	1.5	69.0	-1.5	77.6	-4.5	84.8	-7.0	93.5	-10.0
53.1	4.0	61.8	1.0	70.4	-2.0	79.1	-5.0	86.3	-7.5	94.9	-10.5
54.6	3.5	63.2	0.5	71.9	-2.5	80.2	-5.4	87.7	-8.0	96.3	-11.0
56.0	3.0	64.7	0.0	73.3	-3.0	80.5	-5.5	89.1	-8.5	97.8	-11.5
57.5	2.5	66.1	-0.5	74.7	-3.5	81.9	-6.0	90.6	-9.0	99.2	-12.0
58.9	2.0	67.5	-1.0	76.2	-4.0	83.4	-6.5	92.0	-9.5	100.0	-12.3

By using the dependence formula from Fig. 40, the soil moisture (%FC) corresponding to different values of dT° (with a step of 0.5°C) was calculated. The results are shown in Table 11. In addition to the soil moisture at which the two temperatures equalize, the table includes dT° values at which the pre-irrigation moisture recommended by most researchers is reached. For example, at $dT^{\circ} = -2^{\circ}\text{C}$, soil moisture is about 70%FC, and at $dT^{\circ} = -3.5^{\circ}\text{C}$, it is 75%FC. At $dT^{\circ} = -5.4^{\circ}\text{C}$, the moisture in the 0-60cm layer is about 80%FC, etc. Similarly, the relationship between dT° and soil moisture in different ranges of the soil profile was searched. In terms of accuracy, the results are inferior to those found for the 0-60cm layer. These results confirm the conclusion made in the study that the soil layer 0-60cm is the one on the basis of which the correct irrigation regime for soybeans is carried out, i.e. this layer should also be taken into account for prediction of irrigation.

CONCLUSION

Photosynthetic indicators: Leaf area changes in parallel with leaf mass. There is a linear relationship between them at $R^2=0.968$. LAI under non-irrigated conditions is between 56 and 86% of that – under optimal irrigation. It does not change proportionally to the change in irrigation rates. Soybean FSP increases most rapidly during the period from mass flowering to the end of pod formation (R2-R4). The size of the irrigation rate does not affect the time of occurrence of the maximum. Net photosynthetic productivity in soybean is highest during the vegetative period, then declines rapidly until the beginning of pod formation.

Root system: The main part of soybean roots is located in the surface soil layer 0-20cm (37-44%). The 0-40cm layer contains 67-70% of the entire root system, and 0-60cm - between 86 and 89%. Irrigation through the inter-row leads to a redistribution of the root system in the direction of the wet inter-row, with the ratio of roots from both parts of the row being 3:1 for 0-20cm and 2:1 for 20-60cm, respectively. In terms of total root biomass, the difference is about 1%.

Daily evapotranspiration: It is described by means of a single-peaked curve, (convex parabola), with a maximum during the bean formation period (R3-R4). Under non-irrigated conditions and under irrigation with small irrigation rates, the maximum values are around and slightly above 4.0mm in the first or second decade of July in phase R3. With irrigation with a rate in the range of 70-100%, ET reaches its greatest intensity, and the maximum (over 5-6mm) is recorded at least a decade later.

Evapotranspiration by periods and soil layers: ET during the vegetative period of soybean is mainly formed by the 0-20cm layer (over 50%). The period of flowering-pod formation is characterized by the most intensive ET. The relative share of 0-20cm decreases in contrast to that of the layers below 40cm depth. In all irrigation regimes and periods of vegetation, the 0-20cm layer is of primary importance, which in irrigation with reduced irrigation rates has a higher relative share compared to 20-40 and 40-60cm combined. Irrigation with a full irrigation rate activates ET in the layer 20-60cm and during the reproductive period its relative share reaches and even exceeds the share of the surface soil layer (0-20cm).

Annual ET: With optimal irrigation, annual ET increases by an average of 36%. Reducing irrigation rates by 30% provides from 95-96 to 98% of ET under optimal irrigation. With irrigation at $\frac{1}{2}$ irrigation rates, it reaches between 85 and 92% of the maximum ET, and in years with prolonged droughts during the reproductive period – 79-82%. **The irrigation rate** participates in the formation of ET by an average of 13.3% at the smallest rate, reaching a significant 35.1% at optimal irrigation. The

main part of the maximum irrigation rate (between 73 and 93%) is involved in ET from the layer 0-40cm.

Influence of the irrigation regime on yield and its components: Depending on the irrigation regime and the conditions of the year, the soybean yield varies within relatively wide limits, but they are characteristic of the culture.

• **Positive influence of different irrigation regimes.**

Irrigation during the period of pod formation (R3-R4): This irrigation is most effective. Accelerates vegetative growth and increases internodes, height of plants and beans. It does not unidirectionally affect the number of seeds in one bean and does not change their absolute mass. The increase in yield is mainly due to the number of fully developed seeds.

Irrigation during the pod filling period: This watering usually compensates for a moderate to severe water deficit. It practically does not change the vegetative parameters, but it can influence the reproductive ones. If carried out in early R5, it may slightly increase the number of fully developed seeds. Applied after prolonged and severe drought after the R5 medium, the effect is reversed, due to the remobilization of nutrients to the vegetative parts of the plant. In mid-dry years with significant drought until the end of pod formation, the additional yield is substantial, but if irrigation is given at the end of R5 or later – in R6, the yield also does not increase.

Irrigation during flowering: It is the least effective for soybean development and yield. It positively affects the vegetative components, increasing the number of internodes of the plants, i.e. the productive potential, which, however, in most cases cannot be realized. The yield increases slightly or not at all, and the low share of fully developed seeds (between 46 and 58%) contributes to this.

Irrigation with reduced irrigation rates: Irrigation with very low irrigation rates (30%*m*) practically does not increase yield and is not recommended. At ½ rate, the relative share of fully developed seeds is always the highest. However, it has a low to medium positive impact on yield. In more favorable years, the supply of irrigation water is prevented in each row, while in dry years, it is better to moisten the soil inter-row. Irrigation at a rate of 70%*m* provides near-optimal conditions as the critical 0-40cm soil layer is always moistened. This affects both vegetative and reproductive components of yield. With this irrigation regime, a large number of seeds are planted, but the relative share of fully developed seeds is relatively small (47-60%).

Negative impact of deficit irrigation regime.

Cancellation of watering during the flowering period: It greatly affects the number of internodes on the central stem, leaving the plants shorter. A significant water deficit is not allowed. The formation of the pods proceeds optimally, and 66 and 68% of the planted seeds are fully developed. Yield is close to maximum.

Cancellation of watering during the period of pod formation: Moderate to severe internode number is affected. Drought during this phenophase limits the number of pods and the relative share of fully developed seeds, directly affecting yield. In favorable years, this negative influence is reduced to moderate or weak.

Cancellation of watering during the pod-filling period: The number of fully developed seeds per plant is most affected. Absolute seed weight decreased more significantly when irrigation was canceled at the beginning of the R5 phase. A weak to medium negative impact on yield is observed, and in less favorable years - a strong one.

Negative impact of reduced irrigation rates: The damage caused to plants by irrigation with very low irrigation rates is comparable to that observed under non-irrigated conditions. Irrigation with a rate of ½ has a strong negative effect on the number of pods. The yield is significantly reduced. The reduction of irrigation rates by 30% has a negative impact on a large part of the yield components. It reduces the number of internodes, the number of pods and the number of developed seeds per plant. The absolute weight of the seeds does not decrease. In 50% of cases, the negative impact of the 30% reduction in irrigation rates is highly pronounced.

Yield-water relationship: Regarding the relationship "Yield-irrigation rate" maximum accuracy ($R=0.942$) is achieved by the equation $Y=1-(1-m)^{1.4}$. It is almost the same in the limits $n=1.3\div 1.5$ ($R=0.941$), i.e. in this range of n the results are maximally correct. This increases the universality of the power dependence, without additional compromises in accuracy. The "Yield-annual ET" relationship is most accurately expressed ($R>0.9$) by the two-power formula: $Y=[1-(1-x)^{1.75}]^{5.23}$, as in the zone of real

yield, the linear and one-level formulas give close results. This relationship should be determined based on ET data from the 0-100cm layer. The "*Yield-ET by phenophase*" relationship is not appropriate for soybean. It cannot adequately represent and grade the real sensitivity of the different phenophases, because at the same time there are at least two main phenophases, each of which is specific in terms of water requirements.

Chemical composition of seeds: Irrigation regime has little effect on the crude protein and fat content of soybean seeds. This means that the increase in the yield of these two components should be achieved by increasing the seed yield, by applying an appropriate irrigation regime, and not by looking for an option to increase their content in the seeds. An increase in the size of the irrigation rates is guaranteed to increase the yield of these two components.

Irrigation techniques: The established methods of soybean irrigation - gravity furrow and sprinkler - have a distinct advantage over drip irrigation, as it creates conditions for intensive vegetative growth and establishment of a greater number of beans and seeds per plant, a large part of which remain undeveloped. At the same time, prerequisites are created for laying the plants. The weight of 1000 seeds is also less. The yields are lower compared to the other two methods. This does not exclude its use in soybeans, but considering that in field crops the construction of drip installations creates additional difficulties and limitations, it can be applied in the absence of the possibility of gravity irrigation or raining. Without a definite advantage, the results of sprinkler irrigation of soybeans are slightly better than those of gravity, and this is a confirmation of the beneficial influence of this technique in leguminous crops. This is only about the biological part of the effect and does not include the additional costs related to the technical part (equipment, energy and maintenance). Sprinkler irrigated soybean used water most efficiently, both in terms of ET and irrigation. The most unfavorable results are with drip irrigation.

Economic indicators: With an increase in the irrigation rate in the range from 0 to 40% μ m, the cost price decreases very quickly. As the rate increases in the range of 40-80% μ m, the decrease in cost becomes smaller and smoother, reaching a minimum at the rate of 80% μ m. The further increase in the size of the irrigation rate does not affect the cost price, and it is possible that it will begin to increase again when the irrigation rates are increased above those necessary for conducting an optimal irrigation regime. Compared to all tested irrigation regimes, the net income in the optimal irrigation regime (80%FC) is the highest, i.e. applying any deficit irrigation regime to soybeans can be considered a compromise from an economic point of view. Irrigation while maintaining higher than pre-irrigation humidity (90%FC) does not improve any of the economic indicators.

Irrigation prediction: The indirect determination of ET by the temperature sum method is not inferior in accuracy and reliability to the FAO method, which is why it is recommended as a good option for quick, easy, accurate and free prediction of soybean irrigation. The evaporator method can also be used with success, but with some compromise in accuracy.

There is a linear relationship (at $R^2=0.913$) between dT° values and soil moisture in the 0-60cm layer. It is expressed by the equation: $\delta=64.65-2.88dT^\circ(\%FC)$. At $dT^\circ=-5.4^\circ C$, the moisture in the 0-60cm layer is 80%RH.

CONTRIBUTIONS OF THE DISSERTATION

1. The theoretical probability of the sum of precipitation, the sum of temperature and the sum of air humidity deficit for the period May-September has been determined. The drawn three curves are accurate enough to directly determine the real probability of any of the three meteorological factors for the Plovdiv region. (*scientific-applied*)

2. The parameters of the relationship between the temperature sum and the duration of the phenophases in soybeans were established. The range in which it varies for the course of each of the phenophases and their corresponding duration is determined. Equations are derived. (*confirmatory*).

3. A linear relationship was established between the weight of pods per plant in R6 and that in R8, and the same can be successfully used to predict the yield. (*scientific*)

4. The development of the soybean leaf area was studied, depending on the conditions during the growing season, including the irrigation regime. Based on the obtained data, dependencies were derived as follows:

- Power relationship between LA and the dry biomass of the above-ground part of the plants. It is valid only until reaching maximum LA at $R^2=0.924$. It is expressed graphically by means of a concave parabola. It can be used for predictive purposes. (*scientific*)

- Linear relationship between LA and the dry weight of the leaves at $R^2=0.968$. It can be used to directly calculate the LA from data on the weight of the leaves of a plant. (*scientific*)

- Power relationship between LP and ΣT° at $R^2>0.91$. It can be used to predict the time during which a certain LA is expected to form by tracking the change in ΣT° or $\Sigma T^\circ_{\text{eff}}$ of the air. (*scientific*)

5. The influence of the irrigation regime on LAI was studied in the tested varieties in different years. It has been established that it does not change proportionally to the size of the irrigation rates. A linear relationship was established between LAI and soil moisture in the 0-60cm layer at $R^2=0.704$. It can be used to predict the size of LAI based on soil moisture data. (*scientific*)

6. The influence of the irrigation regime on the FSP was studied. Its dynamics, depending on the water availability of the plants, have been established. A relationship between FSP and dry biomass of plants was deduced at $R^2=0.77$. (*scientific*)

7. The net productivity of photosynthesis was studied in detail, depending on the irrigation regime. Detailed information on its variation by organs and by phenophases was collected. (*scientific*)

8. A detailed study of the soybean root system under irrigation with different irrigation rates was made. Information has been received and provided regarding:

- Its distribution by soil layers, by means of the dry mass of the roots, as well as the relative share of the roots in each soil layer, depending on the irrigation regime. (*scientific-applied*)

- The relationship between the relative irrigation rate and the relative share of roots in the different soil layers ($R^2>0.97$). (*scientific*)

- The layered distribution of the root system in the one-meter soil layer during irrigation in each furrow and through the furrow. (*scientific-applied*)

- A scientifically based criterion for predicting watering and the depth at which the soil should be moistened when irrigating soybeans, established on the basis of the information obtained on the mass and distribution of the root system in depth. (*scientific-applied*)

9. The ET of soybeans was studied in detail in all its aspects, and the daily trend of the different irrigation regimes, its layer distribution (generally for the vegetation period and by phenophases) and the participation of its forming components (by soil layers and for the entire active soil layer). This information is valuable from both a scientific and a practical point of view. (*scientific-applied*)

10. Through the use of appropriate statistical methods, the mechanism of soybean yield formation has been clarified. Based on it, the reasons for changes in yield (yield losses and additional yield) when applying different irrigation regimes were established. Soybean phenophases are graded depending on sensitivity to water stress. The responsiveness of soybean to irrigation during the different phenophases was determined. (*scientific*)

11. The parameters of the relationship *Irrigation rate-yield* in all its varieties have been established, proving that the power formula of the type $Y=1-(1-m)^n$, using the additional yield, is the most representative. With a power indicator $n=1.3\div 1.5$, its accuracy is the same ($R=0.941$). This makes it to a considerable extent universal. (*scientific*)

12. During the analysis of the dependence "Yield-ET" it is established that it is correct only in relation to the annual ET. Reasons why dependence based on ET on phenophases is not recommended, regardless of the high accuracy of the formulas used, are made. (*scientific*)

13. It is proven that the optimal pre-irrigation soil moisture for soybeans is 75-80%FC, valid for the 0-60cm layer. (*scientific-applied*)

14. The topic of irrigation techniques is clarified, firstly sprinkler irrigation is recommended, followed by gravity irrigation and lastly - drip irrigation. (*scientific-applied*)

15. The influence of the irrigation regime on the main chemical components of soybeans has been clarified, and dependencies useful for science and practice have been deduced. It is recommended that the increase in fat and protein yield be achieved by increasing seed yield under an appropriate

irrigation regime, rather than by seeking ways to increase the content of these components in soybean seeds. (*scientific*)

16. A quadratic relationship was established between the relative irrigation rate and the relative cost of production at $R^2=0.94$. It shows that the cost of production reaches a minimum at a rate of 80% m , after which the larger size of the irrigation rate does not affect it, and it is even possible that it starts to rise again when the irrigation rate is increased above the optimum. The economic parameters assuming a periodic water deficit have been determined. It is proven that maintaining a high pre-irrigation humidity above 90%RH does not lower the cost of production, compared to that - at 80%RH. The advantage of sprinkler irrigation and the disadvantages of drip irrigation in terms of economic results are demonstrated. (*for practice*)

17. It is proven that the change in net income follows the trends valid for the relationship *Yield-irrigation rate*, i.e. it is highest when conducting a biologically optimal irrigation regime. A quadratic relationship between the relative irrigation rate and the relative net income was derived at $R^2=0.97$. (*scientific*)

18. It is proven that the indirect determination of ET by the temperature sum method is not inferior in accuracy and reliability to the FAO method, which is why it is recommended as a good option for quick, easy, accurate and free forecasting of soybean irrigation. (*scientific-applied*)

19. The possibilities of using ICT to determine the water status of a soybean crop were studied, and a linear relationship (at $R^2=0.913$) was established between the values of dT° and soil moisture in the 0-60cm layer. At $dT^\circ = -5.4^\circ\text{C}$ it is 80%FC. (*scientific-applied*)