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# INFLUENCE OF THE IRRIGATION REGIME ON THE SOYBEANS (*Glycine max*) ROOT SYSTEM

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## ABSTRACT

**The efficiency of crop irrigation depends largely on the extent of the root system and the corresponding depth at which the soil is moistened by irrigation. The incorrect determination of irrigation rates can cause water stress or unnecessary irrigation costs, and in both cases the efficiency of irrigation decreases. The aim of this work is to study the root system of soybean plants irrigated with full and reduced irrigation rates. The research work was been carried out on alluvial meadow soil from Bulgaria. The variety "Biser" is used. Treatments of the experiment: 1) without irrigation; 2) full irrigation (100%m), 3) irrigation with 70% of the full irrigation application rate (70%m), 4) 50%m, 5) 30%m. Water applications in treatment 2 were realized at 80% of FC (field capacity) pre-irrigation soil moisture in the 0-60 cm soil layer. Irrigation water was applied in short closed furrows. The weight of the roots and their distribution in soil layers were established. For this purpose, soil monoliths with dimensions of 10x35x10 cm at a depth of up to 100 cm have been cut. The irrigation regime had a significant impact on the soybean root weight. The small irrigation rates can increase their dry weight by almost a quarter. The higher irrigation rates can increase the root weight between 64 and 73%. The main part of the soybean roots (37-44%), regardless of the irrigation regime, is located in the surface soil layer 0-20 cm. Most of it is in the 10-20 cm soil layer. In the critical soil layer (20-40 cm), 23% of the roots of non-irrigated plants and 27% of the roots of those irrigated with low irrigation rates (30%) are formed. When applying irrigation rates in the range of 50-100%, the relative share is the same (30-31%). If irrigation rate is calculated to moisten the layer 0-40 cm, it can provide water to 67-70% of the entire root system. If it is calculated for 0-60 cm, it covers 86-89% of the root system. The conclusion is that the criterion for irrigation should be provides the optimal soil moisture in the layer 0-40 cm, and irrigation rates should be moisten the soil layer up to 0-60 cm.**

**Keywords:** soybeans, root system, water deficit.

## INTRODUCTION

Studies on the root system of the crops are relevant, as it performs a variety of functions - from plant support to those related to the water and nutrients uptake from the soil. Regarding the irrigation regime, the knowledge of the root system is the basis for the correct determination of the active soil layer and therefore the most appropriate irrigation rate for the specific conditions.

Studies with soybeans that involve studying its root system are limited. This is most likely due to the difficulties associated with this type of study. However, in the specialized scientific literature, there is information about the distribution of roots in-depth, including in different water supplies of the plants. Already in the 90[s] of the last century, it was found that the main part of the root system of soybeans, supplying plants with water extends to a depth of 50-60 cm (Hutchinson et al., 1983; Schreider, 1989), as Kirda et al. (1994) reporting that individual roots reach a depth of 150 cm. Wanapat and Detpiratmongkol (1989) prove that the responsiveness of soybeans to irrigation is characterized by the depth and spatial location of the root system. The authors found that the roots of optimally irrigated plants have the largest mass. This is possible by applying watering at intervals of 7 days and an irrigation rate of 50 mm. Boquet (1983) found that irrigation does not change the density of the root system in soybeans. For now, research in this direction is limited to various pre-irrigation soil moisture or different intervals between irrigation

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applications. In this direction is the publication of Ashok et al. (2000). According to the authors, the length of the root system in optimally irrigated soybeans can reach 928 cm per plant, measured in phase R3 (pod development). When the level of pre-irrigation soil moisture is reduced to 40% of field capacity (FC), it is 346 cm per plant, and when lowering it to 50% of FC, the length of the roots decreases by 63%. Based on these results, it is concluded that with a deficiency of water in the soil, the root system of soybeans cannot develop well.

However, according to another study (Malagouda et al., 2014), mild water stress (irrigation at intervals of 8 days) provokes its more intensive growth, as a result of which its length exceeds that - at optimal irrigation (irrigation at intervals of 4 days).

Dezortsev (2014) also studied the peculiarities of the growth and distribution of the root system in soybeans, using drip irrigation. When the pre-irrigation soil moisture is maintained above 70% of FC in the layer 0-60 cm, the root dry weight reaches 143 kg/da, with the roots in the layer 10-20 cm being the most (35.7% of the total biomass). At pre-irrigation soil moisture 80% of FC, the dry root weight in 0-60 cm is 183 kg/da, and in the layer 10-20 cm, 40.9% of it is located. The main root mass (81-84%) of soybeans according to the same study is in the layer 0-30 cm.

From the brief literature review, it is clear that there are some discrepancies in the opinions of researchers, which are probably due to the different conditions and methods of conducting the experiments. However, the results of existing research give a general idea of the influence of different levels of pre-irrigation soil moisture on the development of the root system of soybeans, its distribution in-depth and its weight. There is no information in the specialized scientific literature on soybeans about the influence of the regulated water deficit (by reducing the irrigation rates) on its root system. This predetermines the purpose of the present work: to make studies on the root system of soybeans irrigated with reduced irrigation rates.

## MATERIAL AND METHODS

The study, the subject of this work, is part of a long-term field experiment related to research on the soybean irrigation regime. The research work was been carried out in the experimental field of the Agricultural University - Plovdiv (Bulgaria) on alluvial meadow soil. The high-yielding soybean variety “Biser” is used. The experiment was carried out by the block method in 4 repetitions, with the size of the experimental plots 30 $m^2$ and the harvest ones - 10 $m^2$ (Barov, 1982). Sowing is carried out in the third decade of April or the first of May (according to the meteorological conditions of the year). The sowing density is between 20000 and 25000 plants per $m^2$ at an inter-row spacing of 70 cm.

The root system has been studied in the following treatments: 1) without irrigation; 2) full irrigation (100%m); 3) irrigation with 70% of the full irrigation application rate (70%m); 4) irrigation with 50% of the full irrigation application rate (50%m); 5) irrigation with 30% of the full irrigation application rate (30%m). The designation „m” (in brackets) represents the irrigation rate for the optimal treatment. Water applications in this treatment (treatment 2) were realized at 80% of FC (field capacity) pre-irrigation soil moisture in the 0-60 cm soil layer and the irrigation rate is calculated to wet up to FC the entire active soil layer (0-60 cm). Irrigation water was applied by gravity in short closed furrows as the water applications at all treatments were carried out simultaneously, but according to the irrigation rates calculated for each treatment. The time for irrigation was determined by periodically monitoring the dynamics of the gravimetric soil moisture in the active soil layer estimated in intervals of 5-7 days (Atanasov et al., 1972). For maximum accuracy in water application, the irrigation water in the experimental plots was measured with a water meter.

In all treatments of the experiment, the weight of the roots and their distribution in separate soil layers were established. For this purpose, soil monoliths with dimensions 10x35x10 cm (width x length x depth) at a depth of up to 100 cm have been cut.

Practically, the front of each monolith represents ½ of the nutrient area of two neighbouring plants. The soil was separated from the monoliths by washing with the help of a specially made installation. The places from which the monoliths were taken were kept free of weeds throughout the growing season, ensuring that the samples' roots are only those of soybeans.

## RESULTS AND DISCUSSION

For representativeness of the results, the study was carried out in a middle dry year with a sum of precipitation for the period May-September 179 mm and a probability of 72%. Thus, there are conditions for the realization of more irrigation applications, and the negative impact of water stress caused by the reduction of irrigation rates is more pronounced. The data on the amount and distribution of precipitation by phenophases and periods are presented in Figure 1. In addition, the year is warm, with a temperature sum for the period May-September 3363°C and a probability of 11%.

Under these conditions, a total of three irrigation replications were carried out, distributed by periods as follows:

- The first water application was carried out during mass flowering and the beginning of pod development R2-R3;
- The second water application - carried out during the period of pod development and grain filling R4-R5;
- The third water application - carried out during the period of intensive grain filling R5.

The data on the irrigation applications and irrigation rates by treatments are presented in Table 1.

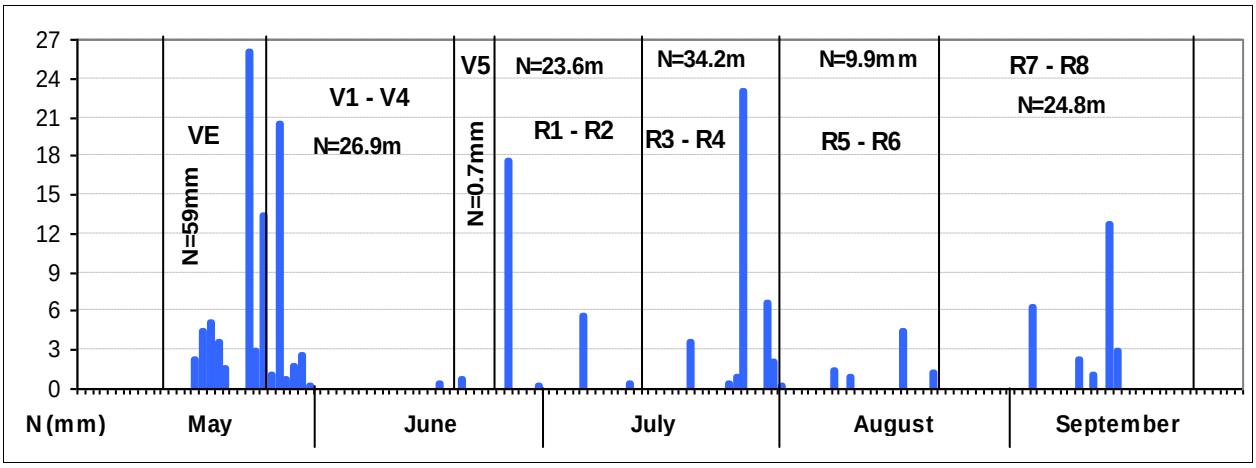



*Figure 1*. Distribution of the precipitations during vegetation period of soybeans

*Table 1*. Irrigation rates at different irrigation regimes

| Irrigation applications | | Irrigation rate (mm) by treatments | | | |
|---|---|---|---|---|---|
| № | period | 100%m | 70%m | 50%m | 30%m |
| 1 | R2-R3 | 44 | 31 | 22 | 13 |
| 2 | R4-R5 | 52 | 37 | 26 | 16 |
| 3 | R5 | 75 | 52 | 37 | 22 |
| Annual irrigation rate (mm) | | 171 | 120 | 85 | 51 |

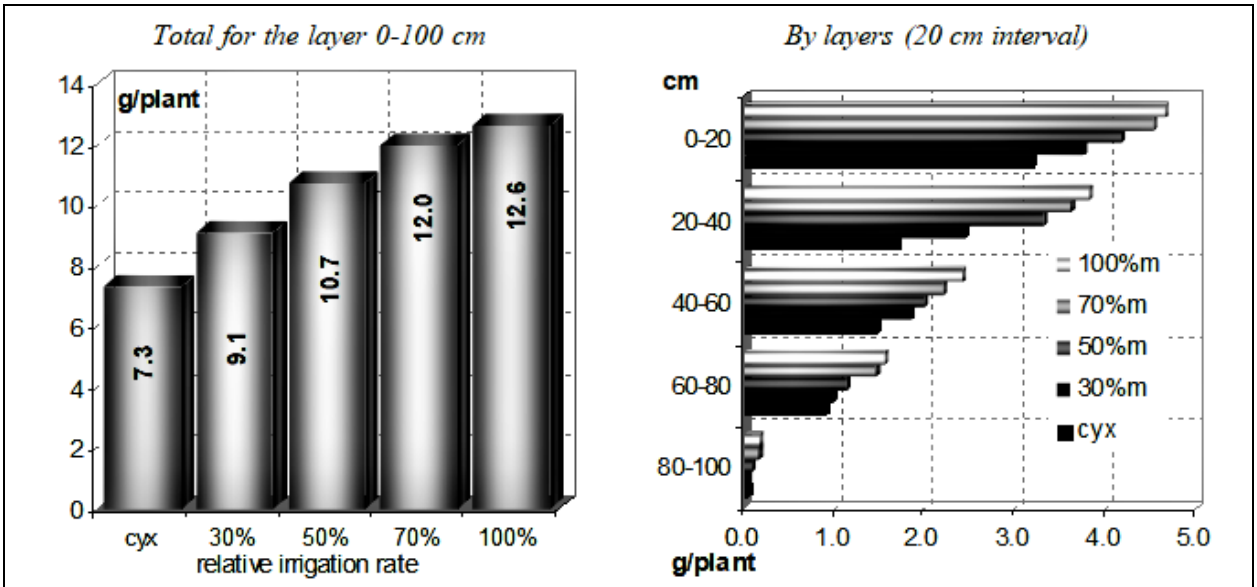
The presented information shows that there are all the necessary conditions to establish the influence of different irrigation regimes on the development and spatial location of the root system in soybeans.

Figure 2 shows the distribution of the root system by soil layers, depending on the irrigation regime, as the data are in absolute values (g/plant) and are valid on average for one plant. The irrigation regime has a

significant impact on the root weight in the entire range of the one-meter soil layer, as in non-irrigated conditions, it is 7.3 g/plant and represents 58% of that in full irrigation treatment.

The positive effect of irrigation is found even irrigation with small irrigation rates, which can increase their dry weight by nearly ¼ (24.4%), reaching 9.1 g/plant. Increasing the irrigation to 50% of the full irrigation application rate leads to an increase in root weight by an additional 22-26% (47-50% more than in non-irrigated conditions). The application of higher irrigation rates additionally increases the root weight, as at 70%m it reaches 12 g/plant and exceeds the established under non-irrigated conditions by 64%. In the full irrigated treatment, this difference is 73% (12.6 g/plant).

If we analyse the impact of water deficit on dry root biomass, the data show that reducing irrigation rates by 30% decreases the weight of roots by 5%, and in saving ½ from irrigation water, the root system is lighter with 13-15%. More significant is the reduction of the values (by 28%) when the irrigation rates are reduced by 70%, and under non-irrigated conditions, it decreases by 42%.




| Soil layer | Without irrigation | 30%m | 50%m | 70%m | 100%m |
|---|---|---|---|---|---|
| 0-20 cm | 3.195 | 3.766 | 4.175 | 4.531 | 4.658 |
| 20-40 cm | 1.709 | 2.452 | 3.313 | 3.623 | 3.825 |
| 40-60 cm | 1.471 | 1.844 | 1.992 | 2.203 | 2.414 |
| 60-80 cm | 0.906 | 0.985 | 1.141 | 1.464 | 1.555 |
| 80-100 cm | 0.038 | 0.056 | 0.098 | 0.162 | 0.175 |
| 0-100 cm | 7.319 | 9.103 | 10.719 | 11.983 | 12.627 |

*Figure 2.* Root system dry weight (g/plant) in separate soil layers depending on the irrigation rate

The irrigation regime has a significant impact on the weight of the roots in separate soil layers, even to some extent outside the theoretical range of irrigation rates (below 60 cm depth). There is a tendency to increase the differences between irrigation regimes with increasing the soil depth, but this is explained by the moistening of different soil depths at different irrigation rates. Since the 0-20 cm layer receives the main part of the precipitation, the root system of soybeans under non-irrigated conditions reaches 3.2 g/plant, which is close to 70% of that obtained with full irrigation (the table in Figure 2). Irrigation with small irrigation rates (30%m) covers only this layer, due to which the roots in it increase their weight by 18% and reach over 80% of those with full irrigation. When irrigated with ½ of the full irrigation rate, the weight of the roots represents 90-94% of the

maximum one and at a rate of 70%m - over 97%. Analyzing the data on the dynamics of soil moisture, it was found that the layer 20-40 cm is critical in non-irrigated conditions and irrigation with small norms. The reason for this is a large number of roots and limited water sources. If this happens at an earlier stage of the vegetation (when the roots increase their weight and length), the growth of the root system is suppressed and it does not reach the typical size of the crop. This is also the case in our case because it is during the period of pod development that the water deficit in this layer is moderate to strong. The results are expected - the weight of the roots is 1.7 g/plant and is only 45% of that - with full irrigation. Slightly more favourable are the conditions in this layer when applying 30% of the full irrigation rate. Although in this case, the irrigation water does not enter this soil layer (20-40 cm), it creates conditions for increasing the share of precipitation for its wetting, which affects the weight of the roots. Thus, in this irrigation regime, it reaches 2.4 g/plant in the layer of 20-40 cm or 64% of the maximum one. These data suggest that limiting the growth of the root system in practice limits the water supply and, at the same time, the uptake of nutrients from this soil layer. This would have an additional negative impact on yield. The application of ½ from the full irrigation rate (25-30 mm) moistens the soil to a depth of about 30 cm, i.e. it has a direct effect on the dynamics of moisture in this layer of the soil. This visibly affects the root weight, which reaches 3.3 g/plant and amounts to 86-87% of the maximum established (3.8 g/plant) in the full irrigated treatment. When irrigated with 70% of the full irrigation rate, the soil moisture in the layer 20-40 cm after the first application and to some extent after the second one and the third one is maintained close to the optimal values, due to which the root system develops well and reaches 3.6 g/plant or 95% of that found in the optimum irrigated soybean.

The 40-60 cm soil layer is used more intensively by the plants at a later stage of the vegetation and for a shorter period. However, it accumulates a sufficient amount of autumn-winter water supply during most of the years. In this way, the plants can make better use of the water accumulated in this layer, and because the roots in it are significantly less, they deplete the available water with less intensity. As a result, the water deficit occurs later, and the difference in the weight of the roots in the studied irrigation regimes is smaller, compared to that of the layer 20-40 cm. The data show that under non-irrigated conditions it reaches 1.5 g/plant or 61% of that found in the full irrigated soybean. At irrigation, with a rate of 30%m the weight of the roots amounts to 76% of the maximum value, and at irrigation with a rate of 50%m - up to 83-86% of the maximum one. Irrigation with a rate of 70%m provides over 90% of the maximum established weight of roots in this soil layer.

As already specified, irrigation water has no direct relation to the water balance of the soil in the layers below 60 cm. There the roots significantly reduce their mass, and in the 80-100 cm layer, their quantity is symbolic. The positive influence of the irrigation regime in this part of the soil profile is indirect and can be explained by the favourable soil moisture until the end of phase R5 when the root system has already stopped its development. These conditions are available in all treatments of the experiment. Thus, the improvement of the conditions in the upper layers of the soil creates conditions for better development of the plants, which has a positive effect on the development of the roots in the deep layers of the soil. If we consider the absolute values, it can be seen that this influence is not so pronounced, but the relative differences confirm the validity of the hypothesis.

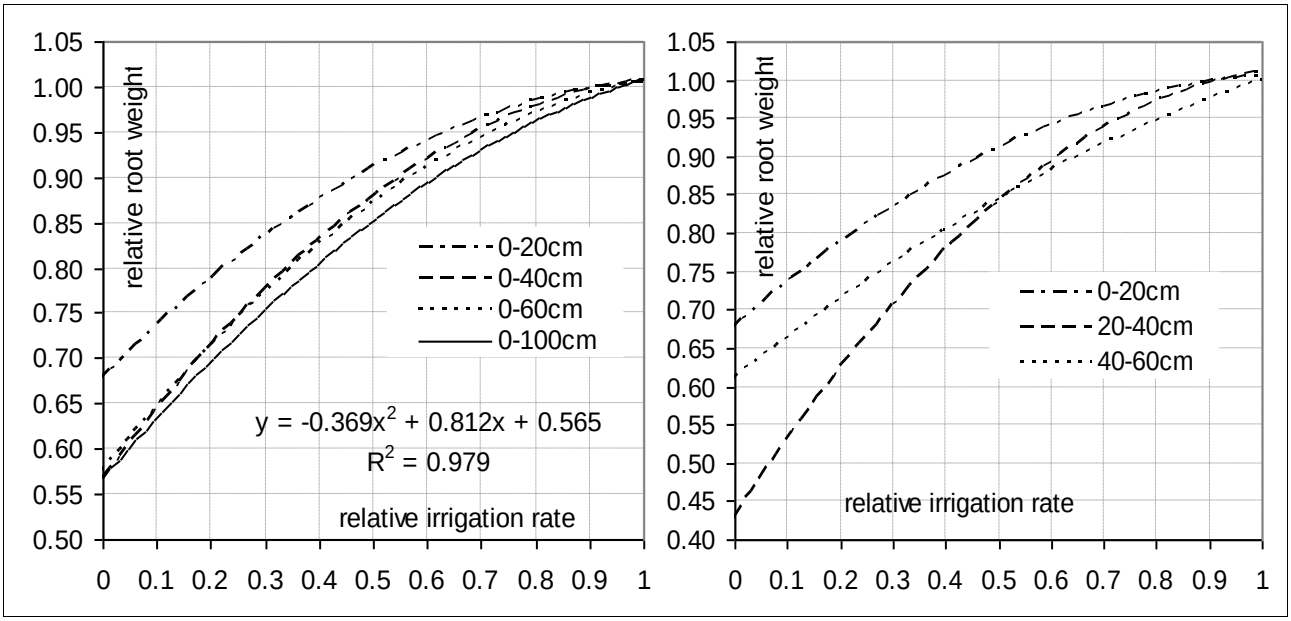



*Figure 3.* The relationship between relative root weight and relative irrigation rate for different soil layers

*Table 2.* Parameters of the relationship between relative root weight and relative irrigation rate for different soil layers

| Soil layer (cm) | Equation of the relationship | $R^2$ |
|---|---|---|
| 0-20 | $Y = 0.678 + 0.603x - 0.276x^2$ | 0.974 |
| 0-40 | $Y = 0.565 + 0.812x - 0.369x^2$ | 0.979 |
| 0-60 | $Y = 0.575 + 0.753x - 0.322x^2$ | 0.985 |
| 0-100 | $Y = 0.568 + 0.698x - 0.257x^2$ | 0.984 |
| 20-40 | $Y = 0.428 + 1.066x - 0.484x^2$ | 0.975 |
| 40-60 | $Y = 0.611 + 0.545x - 0.157x^2$ | 0.992 |

The data show that the step by which the root weight increases with increasing the irrigation rate gradually decreases. This gives reason to look for a relationship between them. According to the available experimental data, a relationship exists for each soil layer. It is square and very strong ($R^2$>0.98). Graphically, it is represented by convex parabolas, which are specific to each soil layer and very accurately describe the influence of the irrigation regime on the change in soybeans root weight. For greater clarity, the results are presented in two graphs (Figure 3), and the parameters are plotted in Table 2. The highest in the coordinate system is the curve describing the relationship valid for the surface soil layer (0-20 cm). This is proof that the conditions in this soil layer are the most favourable for the development of soybean roots, and the size of the irrigation rate has a lesser effect on their weight. This is because the soil moisture in this layer is affected by all the precipitation and realized irrigation rates. The curve describing the relationship for the layer 20-40 cm (right graph) proves the much stronger influence of the irrigation regime on the root weight, confirming the above conclusions. This increases the influence of the irrigation regime in the whole layer 0-40 cm (left graph). Immediately below this curve are the curves describing the dependence in the 0-60 cm layer and the one-meter. This means that the irrigation regime (respectively, the size of the irrigation rates) has a decisive influence on the weight of the roots in the layer 0-40 cm, slightly affects in 40-60 cm and insignificantly - in 60-100 cm. If there is a direct relationship between root mass and seed yield, irrigation rates must be such that, together with seasonal rainfall, they can provide sufficiently high soil moisture in layer 0-40 to phase R5.

Using the values for the absolute root weight in all treatments and in all soil layers, the relative distribution of the soybean root system in depth was established. This information is necessary for the correct determination of the parameters of the irrigation regime, as well as the possibilities for the application of rational irrigation, without unwanted yield losses.

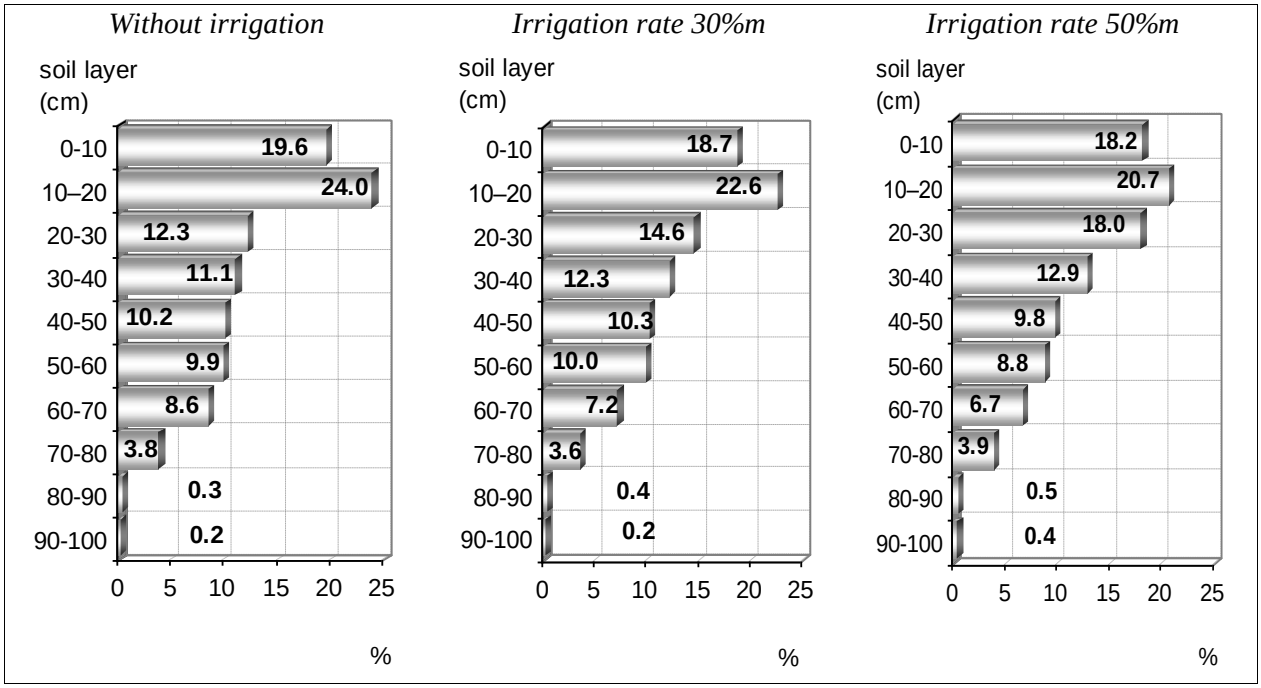



*Figure 4a.* Relative distribution of the root system by soil layers for soybeans depending on the irrigation regime

The data are presented graphically and Figure 4a and 4b. The main part of the soybean roots (37-44%), regardless of the irrigation regime, is located in the surface soil layer 0-20 cm. Most of it is in the 10-20 cm soil layer. This regularity applies to all treatments of the experiment, i.e. it is biologically predetermined. The irrigation regime changes both absolute and relative values, but in a small range. With the improvement of the water supply of the plants, there is a clear tendency to reduce the share of roots by 0-20 cm compared to those in the one-meter layer. Under non-irrigated conditions, they are 44%, at norm 30% decrease to 41%, and at ½ norm, they are 39-40%. When applying the higher irrigation rates (70 and 100%m) the share of roots in this layer amounts to 38 and 37%, respectively. The decrease is against the background of increasing absolute values and is due to a change in the weight measured in the lower layer 20-40 cm, where for reasons already established, the trend is exactly the opposite. In this critical soil layer, 23% of the roots of non-irrigated plants and 27% of the roots of those irrigated with low irrigation rates (30%) are formed. When applying irrigation rates in the range of 50-100%m, the root weight in this soil layer has almost the same relative share - 30-31%. There is a minimal shift of values in the two sublayers (20-30 and 30-40 cm), but it is related to the depth to which each irrigation rate moistens the soil.

Except for the non-irrigated treatment and the one irrigated with small irrigation rates (30%m), no significant and one-way changes of the root mass are observed in the next soil layer (40-60 cm). This is also true at greater depths - 60-80 and 80-100 cm. In general, this layer contains between 18 and 20% of soybean roots.

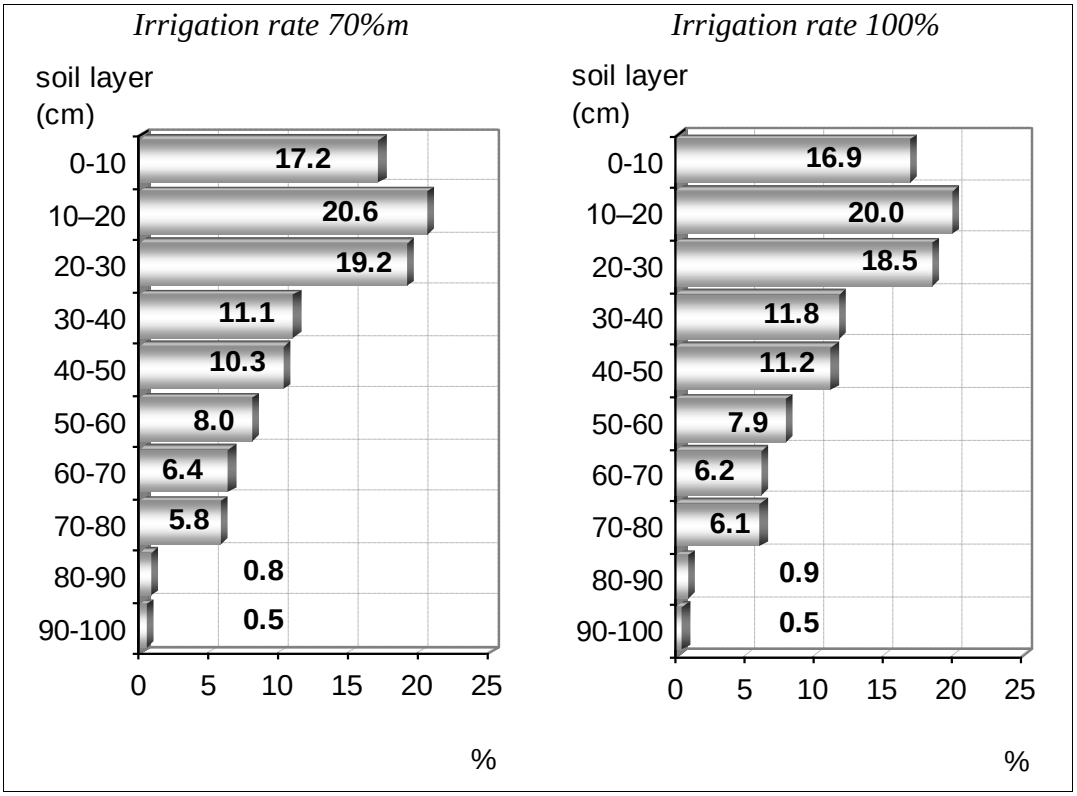



*Figure 4b.* Relative distribution of the root system by soil layers for soybeans depending on the irrigation regime

When determining the parameters of the irrigation regime, it is necessary to know in advance what part of the root system will be provided with a sufficient amount of available water and what part of it will rely on precipitation. To answer these questions, the relative distribution of the root system over a wider range must be considered. According to the analyzes based on experimental data, it can be assumed that for soybeans these are the soil layers 0-40 and 0-60 cm. For both depths, it can be said that the irrigation regime does not significantly change the values. If irrigation rates are calculated to moisten the layer 0-40 cm, it should be known that irrigation can provide water to 67-70% of the entire root system of the plants. If the irrigation rates are calculated for the soil layer 0-60 cm, optimal soil moisture will develop between 86 and 89% of the root system. These data give grounds to conclude that the criterion for scheduling irrigation should be the soil moisture value in the layer 0-40 cm, and irrigation rates should be calculated to moisten the soil to field capacity (FC) in the layer 0-60 cm.

## CONCLUSIONS

The main part of the soybean roots (37-44%), regardless of the irrigation regime, is located in the surface soil layer 0-20 cm. Most of it is in the 10-20 cm soil layer. This regularity applies to all treatments of the experiment, i.e. it is biologically predetermined.

With the improvement of the water supply of the plants, there is a clear tendency to reduce the share of roots by 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 the mass reported in the lower layer 20-40 cm, where the trend is exactly the opposite. In this critical soil layer, 23% of the roots of non-irrigated plants are formed. Under irrigation conditions, the root weight in this soil layer reaches 30%.

There is a close square relationship between the soybean root weight and the irrigation rate.

If irrigation rates are calculated to moisten the layer 0-40 cm, it should be known that irrigation can provide water to 67-70% of the entire root system of the plants. If the irrigation rates are calculated for the soil

layer 0-60 cm, optimal soil moisture will develop between 86 and 89% of the root system. These data give grounds to conclude that the criterion for scheduling irrigation should be the soil moisture value in the layer 0-40 cm, and irrigation rates should be calculated to moisten the soil to field capacity (FC) in the layer 0-60 cm.

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