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INFLUENCE OF WATER DEFICIT ON THE CHEMICAL COMPOSITION OF SOYBEAN GRAINS

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ABSTRACT

With relation to the present issue about the influence of the periodic water deficit on the content and yield of the main chemical components, summarized annual data have been used including years of different characteristics, with droughts in different vegetation phenophases of soybean: very dry, averagely dry and average. The experiment was conducted at the Agricultural University of Plovdiv. The experiment was set in 4 repetitions with a size of experimental plots - 30 m^2, and the crop plots - 10 m^2. Criteria for watering performance was pre-watering moisture of soil at option 5-80% under-soil moisture for the layer 0-60 cm. The irrigation norm for all options was 50 mm. The irrigation norm for option 5 was 150 mm, and for options 2, 3 and 4-100 mm. Irrigation was performed gravitative along short closed furrows. After the completion of all experimental options, there were established the content and yield of the main chemical components in soybean grains - raw fat content, raw protein, raw fibres, raw ash and non-nitrogen extracted substances. Watering cancellations in the period of seed filling decrease the raw protein content. Watering cancellation in the bean formation period has a negative influence on protein content in soybean or does not influence it at all. Watering cancellation during the reproductive period decreases raw protein yield, which leads to a decrease in grain yield. Regarding raw fats, the most favourable is the water cancellation in the period of seed filling which favours growth in their content. Watering cancellation in the period of seed filling leads to a more significant decrease in lysine content. Despite the watering cancellation in a particular phase, the application of the other two waterings increases carbohydrate content in soybean grains compared to that obtained in non-watering conditions.

Keywords: soybean, evapotranspiration, water deficit, protein, fat.

INTRODUCTION

Soybean is an important proteinoid-bearing crop culture. Its grains contain many valuable substances. According to Malikov and Vasilchenko (2014), Peshkova et al. (2016), Hudson (2022) point out that the protein content is 37-42%, and fats content is by 19-22%. These two components determine the constant growth of soybean areas all over the world. The increase in grain yield, which is economically justified, would lead to a decrease in the production self-value, including protein and fats. This is achieved via the application of the appropriate irrigation regime. According to numerous studies, there is opposite dependence between the compositions of these two components (Adamen, 1984; Kirnak et al., 2010; Li et al., 2022).

There are different statements related to the influence of the irrigation regime on the chemical composition of soybean grains. According to numerous authors, plant water security rate does not influence the chemical components and others claim that it influences all or some of them. From a scientific point of view, there is an interest towards the influence of water deficit during particular phenophases on the chemical composition of soybean grains because the cancellation of watering is the easiest and at the same time effective way of saving water for irrigation (Jin et al., 2022; Li et al., 2022; Ogunkanmi et al., 2022; Antunes Rodrigues et al., 2023).

Studies related to the influence of the periodic water deficit on protein content in soybean grains are still few. According to Pritoni et al. (1990) and Abbas et al. (2013),

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protein content is the lowest during soil drought in the stage of seed filling (R5-R6). It is a little higher during drought in bean formation (R3-R4), followed by the flowering stage (R1-R2). The lowest influence of water stress is during the vegetative period, or rather during phase 4 - leaves. In other words, the latest the drought is, the strongest the influence is. Opposite results were published by Demirtas et al. (2010). According to them, protein content is the highest during drought in the period of seed filling. The same conclusion was registered by Ghassemi-Golezani and Lotfi (2013), but they considered critical the whole reproductive period. Ashraf et al. (2013) in their publication established that the maximum protein content was obtained at non-irrigation conditions (up to 41.2%). Admitting moderate water deficit with a cancellation of waterings during one phase decreases in addition protein content in grains with no significant difference between the separate periods (between 39.2 and 39.6%).

Regarding the influence of water deficit on fat content in soybean grains, scientific publications are also controversial. Abbas et al. (2013) proved that fat content was the lowest (20.8%) at water stress during the period of seed filling. Authors reported influence on their quantity, as well as on their quality. This was proposed two decades ago by Pritoni et al. (1990). The opposite position had Demirtas et al. (2010), claimed that fat content in grains was the highest during drought in the period of their filling. According to Ghassemi-Golezani and Lotfi (2013), drought during the reproductive period influences negatively fat synthesis, which decreases its yield in a unit of area. Ashraf et al. (2013) presented more thorough information. According to them, the least negative effect on fat yield has the cancellation of watering during the flowering stage or the vegetative period. The presence of water deficit during phases V and R1-R4, V and R5-R6, as well as during the whole vegetative period (R1-R6), influences fat content, which decreases under 20%, and at non-watering conditions fats lower up to 17%. Authors explain the received results mainly with the influence of the irrigation regime on the duration of the seed filling stage (R5-R6). Supplying favourable soil moisture increases the continuation of this period giving a possibility for larger fat accumulation. For the same reason, at non-watering conditions fat content is the lowest.

The present research study aims at establishing the influence of the periodic water deficit, with the cancellation of one watering during some different vegetation phenophases, on some components in the chemical composition of soybean grains.

MATERIAL AND METHODS

With relation to the present issue about the influence of the periodic water deficit on the content and yield of the main chemical components, summarized annual data have been used including years of different characteristics, with droughts in different vegetation phenophases of soybean: very dry (with drought in the period R2-R5), averagely dry (with drought in phenophases R2 and R5-R6) and average (with drought in the period R3-R6). The quantity and distribution of vegetation precipitations during all experimental years allowed the performance of three waterings. Thus, there was a possibility for the cancellation of one watering during a particular phenophase and the performance of two waterings during the rest phenophases. In other words, it could be traced back to the phenophase where water deficit influences the content and yield of the particular chemical components. The experiment was conducted at the Agricultural University of Plovdiv on alluvial-meadow soil. Experimental options were as follows: 1) without irrigation; 2) cancellation of first watering; 3) cancellation of second watering; 4) cancellation of third watering; 5) optimum irrigation (all waterings completed). The experiment was set in 4 repetitions with a size of experimental plots - 30 m^2, and the crop plots - 10 m^2. Biser variety was used (averagely late). Criteria for watering performance was pre-watering moisture of soil at option 5-80% under-soil moisture for the layer 0-60 cm. The irrigation norm for all options was 50 mm. The irrigation norm for option 5 was 150 mm and for options 2, 3 and 4 - 100 mm. Irrigation was performed gravitative along short closed furrows. After the completion of all experimental options, there were established the content and yield of the main chemical components in soybean grains as follows:

The raw fat content was established by the residual method of Soxhlet (1879), through the extraction with petroleum ether.

The raw protein was determined after the determination of the total nitrogen via mineralizing the plant samples with concentrated sulphur acid and selenium used as a catalyst by the method of Kjeldahl (1883), followed by distillation of the mineralized sample in Parnas-Wagner apparatus and multiplication of the received values of the common nitrogen by coefficient 6.25.

The raw fibres were determined by the method of Heneverg and Shtoman via the operation of plant material with acid and base solutions having particular concentrations at particular conditions (*ISO 5498/99*).

The raw ash was determined via slow burning of the sample at a temperature of 550-600°C.

Non-nitrogen extracted substances were received by the formula NES = 100 - raw protein + raw fats + raw fibres + raw ash.

The yield of the tested chemical components was determined with the multiplication of the per cent content of the component and the relevant grain yield.

RESULTS AND DISCUSSION

Influence of the short-term water deficit on the content and yield of raw protein in soybean grains.

Results related to the influence of the periodic water deficit on the content and yield of raw protein from soybean are presented in Table 1. They outline the specificity of the separate vegetation periods and the alternation of raw protein content in the conditions of short-term drought. It was completely proved that watering cancellation during the seed filling period (R5 and R6) leads to the highest decrease in protein content. The year characteristics have additional influence. For example, the decrease compared to the non-irrigated soybean during average years was 0.7-1.8%, during average dry - 2.2%, and during very dry - it reached 7.4%. Watering cancellation during the bean formation period (R3-R4) had an insignificant negative influence on protein content in grains, or it does not influence. To some extent, it compensated for more significant losses of grain yield. Compared to the non-irrigated variant, the decrease was up to 1.7%. In the case of watering cancellation during the flowering stage (R2), the protein conten also decreased, as in dry years the decrease reached up to 2.7%. Compared to the optimum irrigated soybean, watering cancellation till the beginning of phenophase R5 supplied higher protein content while watering cancellation after that led to the same or lower values than those at optimum irrigation. The effect of watering cancellation in separate phenophases on raw protein content is related to a great extent to the direction of assimilate motion in the relevant phenophase. It led to a greater difference during the seed-filling period compared to the previous phenophases. On the other hand, Ashraf et al. (2013) explained the higher values with the influence of water deficit on metabolism, which was directed to increased synthesis of protein in grains.

Table 1. Content ad yield of raw protein at the cancellation of 1 watering during different vegetation phenophases

Treatment		CP %	CP kg/da	To dry		Warranty	To optimum		Warranty	GD kg/da
				± kg/da	%		± kg/da	%		
Drought during R2 and R5-R6 averagely dry years										
1	Without irrigation	42.52	55.5	St.	100.0	St.	-83.7	39.9	C	5%=11.3 1%=15.1 0.1%=20.0
2	Cancellation during R2	42.78	112.2	56.7	202.1	C	-27.1	80.6	C	
3	Cancellation during R4	43.09	110.3	54.8	198.8	C	-28.9	79.2	C	
4	Cancellation during R5	40.36	118.9	63.5	214.3	C	-20.3	85.4	C	
5	Without cancellation	40.79	139.2	83.7	250.9	C	St.	100.0	St.	
Drought during R2-R5 dry years										
1	Without irrigation	42.22	46.0	St.	100.0	St.	-75.4	37.9	C	5%=12.1 1%=16.2 0.1%=21.5
2	Cancellation during R2	39.54	105.9	59.9	230.1	C	-15.5	87.2	C	
3	Cancellation during R4	41.18	110.0	64.0	239.0	C	-11.4	90.6	C	
4	Cancellation during R5	34.79	84.8	38.8	184.2	C	-36.6	69.8	C	
5	Without cancellation	38.20	121.4	75.4	263.8	C	St.	100.0	St.	
Drought during R3-R6 average years										
1	Without irrigation	41.18	88.5	St.	100.0	St.	-51.0	63.5	C	5%=9.8 1%=13.1 0.1%=17.4
2	Cancellation during R4	39.50	133.2	44.7	150.4	C	-6.3	95.5	n.s.	
3	Cancellation during R5	40.49	110.5	21.9	124.8	C	-29.1	79.2	C	
4	Cancellation during R6	39.37	106.4	17.8	120.1	C	-33.1	76.3	C	
5	Without cancellation	38.55	139.5	51.0	157.6	C	St.	100.0	St.	

Alternations in raw protein content in soybean grains influenced protein yield taking into account the obtained grain yield (Table 1). Data show that the high protein yield has to be supplied through increased grain yield, not through an increase in its concentration in them. Both options were difficult to be accomplished simultaneously. Experimental data, as well as some references, reported that they altered in opposite directions, the high soil moisture increased grain yield but decreased protein content in them, and vice versa. For example, all tested irrigation regimes increased statistically proven protein yield compared to that under non-irrigation conditions. During drought years this increase was around or over two times, and during average or favourable years - it was 20-50%. Watering cancellation during the reproduction period led to a decrease in grain yield, as it effects negatively raw protein yield. This influence was expressed more clearly in the dry experimental years, as losses were within diapason of 15-20%. In an extremely dry year, during the seed filling period, losses could exceed 30%.

Influence of short-term water deficit on the content and yield of raw fats.

Watering cancellation had a weaker influence on raw fat content compared to raw protein (Table 2). The most favourable was water cancellation in the seed filling period (R5-R6). It not only had a negative effect but also increased raw fat content compared to all other irrigation regimes, including the non-irrigation option (between 0.5-1.0%) and the optimum irrigation option (between 0.3-1.9%). Being relatively small, differences were most significant in the dry years followed by the average-dry years, and the smallest was in the average years. Taking into account that there were no established significant differences in phenophase duration (R5-R6 in particular) at different irrigation regimes, other differences reported by Ashraf et al. (2013) were not established. According to data in Table 2, watering cancellation during the flowering stage (R2) did not alter raw fat content compared to the optimum variant. Its alternation after watering cancellation during bean formation (R3-R4) was weak and varied.

Table 2. Content and yield of raw fats at the cancellation of 1 watering during different vegetation phenopases

Treatment		CF %	CF kg/da	To dry		Warranty	To optimum		Warranty	GD kg/da
				± kg/da	%		± kg/da	%		
Drought during R2 and R5-R6 averagely dry years										
1	Without irrigation	20.21	26.4	St.	100.0	St.	-43.4	37.8	C	5%=5.4 1%=7.3 0.1%=9.6
2	Cancellation during R2	20.26	53.1	26.7	201.4	C	-16.7	76.1	C	
3	Cancellation during R4	20.42	52.3	25.9	198.2	C	-17.5	74.9	C	
4	Cancellation during R5	20.73	61.1	34.7	231.6	C	-8.7	87.5	B	
5	Without cancellation	20.45	69.8	43.4	264.6	C	St.	100.0	St.	
Drought during R2-R5 dry years										
1	Without irrigation	21.48	23.4	St.	100.0	St.	-41.9	35.8	C	5%=6.9 1%=9.2 0.1%=12.2
2	Cancellation during R2	21.01	60.5	37.1	258.5	C	-4.8	92.6	n.s.	
3	Cancellation during R4	19.38	51.8	28.3	221.1	C	-13.6	79.2	C	
4	Cancellation during R5	22.43	54.6	31.2	233.4	C	-10.7	83.7	B	
5	Without cancellation	20.55	65.3	41.9	279.0	C	St.	100.0	St.	
Drought during R3-R6 average years										
1	Without irrigation	21.81	46.9	St.	100.0	St.	-32.6	59.0	C	5%=5.4 1%=7.3 0.1%=9.6
2	Cancellation during R4	22.45	75.7	28.8	161.4	C	-3.8	95.2	n.s.	
3	Cancellation during R5	22.57	61.6	14.7	131.3	C	-17.9	77.5	C	
4	Cancellation during R6	22.73	61.4	14.5	131.0	C	-18.1	77.3	C	
5	Without cancellation	21.96	79.5	32.6	169.5	C	St.	100.0	St.	

Taking into account the relatively low influence of the periodic water deficit on raw fat content in soybean grains, yield from a unit of area altered simultaneously with grain yield. In average-dry and dry years the increase of fat yield towards that, obtained from non-irrigated soybean, was around or over two times. The drier the year was, the more significant the differences were. They were statistically proven. A weaker positive effect was registered at water cancellation during the bean formation period, but as was already mentioned, it is important for the final grain yield, as well as for raw fat yield. In the favourable experimental years, differences were also statistically proven, but they were relatively smaller due to the disproportional increase in yield at non-irrigation conditions and that at irrigation options as the values were in favour of the dry option. Losses in raw fat yield at one watering cancellation did not exceed 25%, vat varied depending on the year and phenophase of water deficit.

Results related to raw fat yield proved that it had to be increased towards grain yield, not towards increasing their content in grains.

Influence of watering cancellation on content and yield of lysine.

Being criteria for nutritive qualities of grains, lysine content and yield are important, especially for the use of soybean in the food industry or animal breeding. According to data in Figure 1A, irrigation lowered the content of this amino acid in soybean grains. It lowered more significantly after watering cancellation during seed filling. Compared to the non-irrigated soybean, the cancellation of late watering was performed in an important period and at optimum conditions of soil moisture. This altered plant metabolism, which resulted in lower content of lysine. This effect was enforced in the years with a dry reproduction period, especially in the seed-filling period.

Figure 1B presents information for lysine yield by years and options. Compared to options 1 and 5 (dry and optimum), at options with watering cancellation, it decreased due to the decreased grain yield. There was observed the more strongly expressed negative effect of watering cancellation during seed filling, especially in the dry years. Differences were statistically proven about the non-irrigated option, as well as the optimum irrigated variant. Lysine yield also decreased at flowering and bean formation phenophases. It was more weakly expressed, and in practice was not influenced by the year conditions.

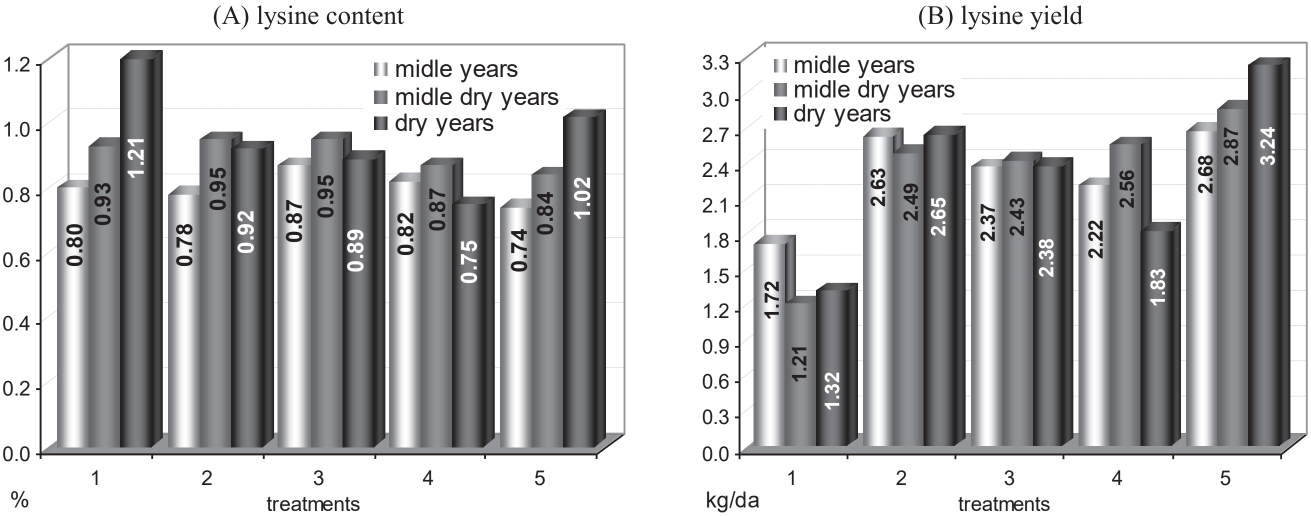

Figure 1. Influence of watering cancellation on content and yield of lysine

Influence of watering cancellation on content and yield of non-nitrogen extracted substances.

Data related to carbohydrate content and yield at watering cancellation by phenophases is presented in Table 3.

Despite the phase of watering cancellation, the performance of the rest two waterings increased the content of carbohydrates in soybean grains compared to that at non-watering conditions. The increase was more strongly expressed in average-dry and dry experimental years. There was a difference in the results by phenophases. In the dry years, the watering cancellation during seed filling increased carbohydrate content, which was higher than that of the optimum variant. Regarding this chemical component, it is well known that its synthesis is related to the direction of assimilating motion in plants. In other words, the low soil moisture leads to levels of plant growth dormancy and maximum content of carbohydrates in yield. The watering cancellation in this vegetation stage had a positive effect. In the favourable years, regarding precipitation, there were one or two waterings in stages R5-R6 for the optimum variant. In the case of two waterings, water deficit was not allowed as the deficit in dry years. A similar was the effect after watering cancellation during the previous phases, but it was more weakly expressed. This effect was due to the remained water deficit. In the dry years, it could not be fully compensated by the subsequent waterings.

Table 3. Content and yield of non-nitrogen extracting substances at the cancellation of one watering in different vegetation phenophases

Treatment		NES %	NES kg/da	To dry		Warranty	To optimum		Warranty	GD kg/da
				± kg/da	%		± kg/da	%		
Drought during R2 and R5-R6 (2003) averagely dry										
1	Without irrigation	23.13	30.2	St.	100.0	St.	-47.3	39.0	C	5%=6.3 1%=8.5 0.1%=11.2
2	Cancellation during R2	25.07	65.7	35.6	217.8	C	-11.7	84.9	C	
3	Cancellation during R4	24.57	62.9	32.7	208.4	C	-14.5	81.2	C	
4	Cancellation during R5	25.20	74.2	44.1	246.0	C	-3.2	95.9	n.s.	
5	Without cancellation	22.69	77.4	47.3	256.6	C	St.	100.0	St.	
Drought during R2-R5 (2007) dry										
1	Without irrigation	20.91	22.8	St.	100.0	St.	-57.4	28.4	C	5%=7.6 1%=10.2 0.1%=13.5
2	Cancellation during R2	23.25	67.0	44.2	293.8	C	-13.2	83.5	B	
3	Cancellation during R4	22.90	61.2	38.4	268.4	C	-19.0	76.3	C	
4	Cancellation during R5	26.12	63.6	40.9	279.3	C	-16.5	79.4	C	
5	Without cancellation	25.22	80.1	57.4	351.7	C	St.	100.0	St.	
Drought during R3-R6 (2006) average										
1	Without irrigation	20.78	44.7	St.	100.0	St.	-38.6	53.6	C	5%=5.6 1%=7.5 0.1%=9.9
2	Cancellation during R4	22.80	76.9	32.2	172.1	C	-6.4	92.3	A	
3	Cancellation during R5	21.50	58.7	14.0	131.3	C	-24.6	70.4	C	
4	Cancellation during R6	20.99	56.7	12.0	127.0	C	-26.6	68.1	C	
5	Without cancellation	23.01	83.3	38.6	186.4	C	St.	100.0	St.	

Regarding the yield of non-nitrogen extracting substances, the water deficit depended on the real grain yield and it was corrected by their content. Despite the watering cancellation, yield grew statistically proven compared to that - at non-irrigation conditions. In the average - dry and dry years its increase was over two times. In the years with an average amount of precipitation yield was significantly weaker. After watering cancellation In the period of seed filling it was 30%, and after cancellation during bean formation - 72%. The tendency was the achievement of fewer losses of yield after the first watering cancellation. Nevertheless, on the grounds of the present information, a conclusion could not be done.

Influence of watering cancellation on the content and yield of raw fibres and raw ash.

According to the results of the chemical analysis, the watering cancellation in any phenophase of the soybean reproduction period did not lead to clearly expressed and one-directed alternation in the content of raw fibres (Figure 2A). With a few exclusions, it was within the diapason 10-12% and conformed with the norm of this particular crop culture. The weak variation of raw fibre content at the separate options was the main reason that raw fibre yield depended on grain yield (Figure 2B).

Regarding raw ash content in soybean grains, the annual conditions had a stronger influence on watering cancellation during R3-R6 period, while the watering cancellation during mass flowering variations was less (Figure 3A). It was because this water deficit led to insignificant soil drought, which later was compensated by waterings during R3-R6 period. There was a more significant negative effect after watering cancellation during bean formation, followed by the seed-filling period. The influence of the year influenced similarly the quantity of raw ash from a unit of area. The performance of two waterings, instead of three, decreased the quantity of this chemical component compared to that at optimum irrigation, it increased the influence of the year. The strongest effect had the water deficit during bean formation, followed by those during seed filling, and the weakest effect - was after watering cancellation during the mass flowering period (Figure 3B).

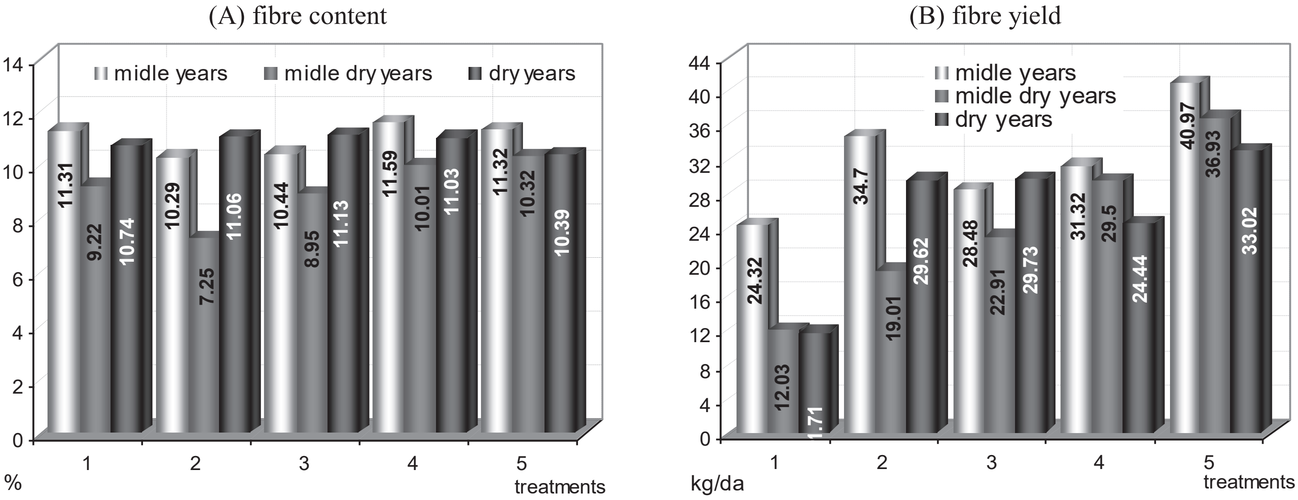

Figure 2. Influence of watering cancellation on the content and yield of raw fibres

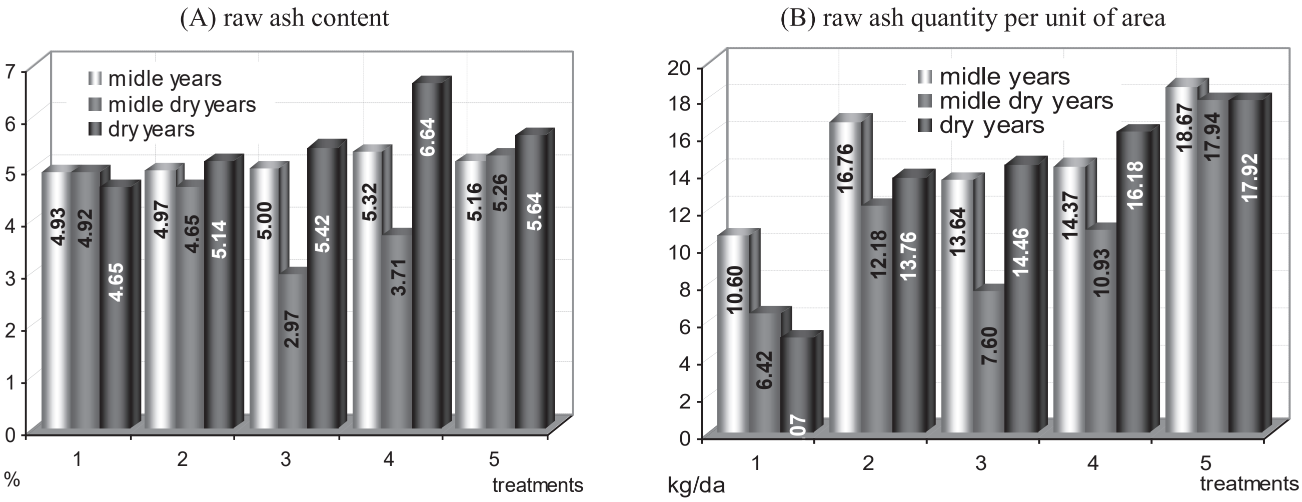

Figure 3. Influence of watering cancellation on raw ash content and its quantity per 1da

CONCLUSIONS

Watering cancellations in the period of seed filling (R5 and R6) decrease significantly the raw protein content. Year conditions have additional influence. The drier the year is, the lower the values are. Watering cancellation during the grain formation period has an insignificant negative influence on protein content in soybean grains or does not influence it at all. To some extent, it compensates the losses of grain yield.

Watering cancellation during the reproductive period decreases the raw protein content, which leads to a decrease in grain yield. This influence is more clearly expressed in drier years. Losses are within the diapason of 15-20%, but they could exceed 30% in the presence of more extreme drought in the period of seed filling.

Regarding raw fats, the most favourable is the water cancellation in the period of seed filling (R5-R6), which favours growth in their content. The drier the years are, the bigger the difference sare. Watering cancellation during the flowering period (R2) does not change raw fat content compared to its change at optimum irrigation. Alternation in raw fat content after watering cancellation during bean formation (R3-R4) is weak and varies.

Raw fat yield from a unit of area is altered at the same time as grain yield. An increase in fat yield has to be towards an increase in grain yield, and not towards searching ways for increasing fat content in grains.

Watering cancellation in the period of seed filling leads to a more significant decrease in lysine content. It is due to a change in plant metabolism. This effect is strengthened over the years with strong drought during the reproductive stage, more particularly during the seed-filling stage.

Despite the watering cancellation in a particular phase, the application of the other two waterings increases carbohydrate content in soybean grains compared to that obtained in non-watering conditions. It is stronger expressed in dry years. Watering cancellation in the seed-filling stage significantly increases carbohydrate content. It is due to a change in the direction of assimilating motion in the plant. The decrease of soil moisture to some extent gives the possibility for obtaining maximum content in yield.

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