CROP CAPACITY AND QUALITY OF SOYBEAN GRAIN DEPENDING ON SEED SOWING RATE AND WIDTH OF INTER-ROWS

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ABSTRACT:

The aim of the conducted research was to substantiate the elements of soybean growing technology, which would ensure high crop capacity and grain quality. On row crops of ultra-early-maturing soybean cultivar Annushka and early-ripening cultivar Bajka, the highest crop grain capacity in the experiment – 1.85 and 2.18 t/ha was obtained at the rate of seed sowing – 1.2 and 1.0 million items/ha, correspondingly. On variants with inter-rows of 45 cm, the highest crop grain capacity of these cultivars – 1.59 and 1.84 t / ha – was obtained at the sowing rates of 1.1 and 0.9 million items/ha, accordingly, and with 70 cm inter-rows – under sowing 1,0 and 0.9 million items/ha – 1.27 and 1.35 t/ha. The protein content in Annushka soybean grain was by 1.0–1.1 % higher than in Bajka cultivar. Thickening of crops by increasing the seeding sowing rate and expanding inter-rows width led to the increase in protein content in grain. The highest protein harvest on the average over the years – 764 kg/ha was observed on crops of soybean cultivar Bajka under the combination of seed sowing rate of 1.0 million items/ha with the width of inter-rows of 15 cm. On Annushka crops the largest protein harvest – 679 kg/ha was received under the same inter-row width, but at seed sowing rates of 1.2 million items/ha. On variants with 45 cm of inter-rows width, the largest soybean protein harvest of Bajka and Annushka cultivars – 647 and 585 kg/ha was observed under the seeding rates of 0.9 and 1.1 million items/ha, correspondingly. The oil content in grain of both soybean cultivars decreased with increasing sowing rate and expansion of inter-rows. The soybean cultivar Bajka had a higher oil content in grain in the context of all combinations of inter-rows width with seed sowing rate. On the average by the years, seed sowing rates and variants of inter-rows width, the oil content of Baika soybean grain was by 2.7 % higher than that one of Annushka. The largest oil harvest from 1 ha of both soybean cultivars under all sowing rates was provided by seed sowing with 15 cm inter-rows width. The oil harvesting from 1 ha on variants, with inter-rows width of 15, 45 and 70 cm averaged 334, 286 and 217 kg/ha, correspondingly. As for the oil harvest from 1 ha among the studied cultivars, the cultivar Bajka prevailed.

Keywords:

soybean, sowing rate, inter-row, oil content, protein content.

Article Received: 18 October 2020, Revised: 3 November 2020, Accepted: 24 December 2020

Introduction

Among all crops, soybean has the highest total protein and oil content, which reaches 70 % [1]. Along with the high potential of grain productivity, it determines the great demand for this crop both in Ukraine and in the world. The unique composition of organic, mineral, biologically active substances and their functional properties determine the versatility and universality of this crop. These are benefits of soybean that have contributed to a significant expansion of sowing areas under this crop. Today, the world soybean production is almost 352 million tons and the soybean leaders are the United States, Brazil, Argentina, which harvested record 286 million tons of soybean, which comprises 82 % of world production in 2016/17 [2].

The sowing area under this crop has reached the maximum level, as its further increase will be due to the detriment of other crops, so the increase in gross grain production of this crop should be due to increasing the level of crop grain capacity and improving grain quality, but not due to sowing area expanding.

The lack of cultivar technologies for soybean cultivation causes a significant shortage of this crop grain. That is why it is important to improve the components of cultivation technology based on a comprehensive comparison of their variants. Among the elements of cultivation technology that are easy to operate, sowing methods and seed sowing rates are extremely important. They

determine the whole technological complex of growing this crop and significantly affect its crop capacity [3].

Recently, the soybean processing industry aimed at feed and food production has been developing intensively, so the demand for high-quality seeds is growing rapidly. Therefore, improving the elements of the technology of growing this crop along with increasing crop grain capacity should include improving its quality.

Analysis of literary sources, problem setting. Soybean capacity of grain is determined by the average productivity of one crop and their number per unit area. Therefore, in specific conditions it is necessary to determine the optimum combination of these indicators, which would ensure the formation of the highest crop grain capacity per unit area [4]. In this regard, a number of scientists note that the seed sowing rate has a greater effect on soybean crop capacity than the method of sowing [5].

The existing recommendations as to the optimum combination of sowing rate and soybean sowing method are quite contradictory and it is natural, as they are designed for different cultivars , in various soil and climatic conditions, as well as for specific parameters of cultural practices: sowing time, seed wrapping depth, nutrition system, etc. However, all researchers agree that soybean grain capacity is reduced in both thinned and thickened crops.

In thickened crops, the intensity of photosynthesis deteriorates and soybean not only accumulates less nutrients, but also becomes sensitive to lodging [6]. At the same time, thinned crops are overgrown with weeds, the lower beans and branches on plants are laid closely to the soil surface, which creates unfavorable conditions for the growth and development of soybean plants, complicates their mechanized harvesting [7].

The excessive evaporation of soil moisture is noticed in thinned crops .Irregular ripening of beans, breakage of branches under the influence of wind, precipitation and mass of beans occur, which leads to significant yield losses. Increasing the seed sowing rate leads to a decrease in the survival of plants during the growing season. As a result their differentiation by growth and development takes place and competition between them intensifies [8–12].

According to researchers A.I. Baranov and O.S. Stupnitska [13] the soybean of early-ripening cultivars are recommended to be sown with a sowing rate of 0.8 million items/ha. The similar opinion is held by O.G. Milenko [14], who notes the advantage of this seeding rate for early – maturing cultivars. The latter advises to increase the seeding rate to 0.9 million items /ha for fast-ripening varieties.

When choosing the rate of seeding, it is necessary to take into account the supply of plants by nutrients and moisture. While optimizing the system of crop nutrition and sufficient moisture, it is advisable to increase the seeding rate [15].

It is found that late-maturing tall soybean cultivars with a spreading bush shape, which are well branched and form many leaves, should be sown with a lower seed sowing rate and wider inter-rows. Early-maturing low-growing cultivars with a compressed shape of the bush, which are less branched, on the contrary, should be sown with a higher seed sowing rate and narrower inter-rows [16].

In the conditions of moisture deficiency, a wide-row method of sowing with 45 cm inter-rows width in combination with a seed sowing rate of 0.3 million items/ha is preferred [17]. Under the conditions of sufficient moisture, soybean should be sown in the same way with a seed sowing rate of 0.5 million items/ha [18].

On deep chornozem with a low content of humus, wide-row sowing with 45 cm inter-rows also provided the advantage over the conventional row method [19, 20]. The studies [3] have shown the advantage of row sowing with 15 cm inter-rows in combination with a seed sowing rate of 0.8 million items/ha. The expansion of inter-rows up to 45 cm led to a decrease in crop capacity by 17 % [3, 21]. The equal effect of the conventional row and wide-row sowing method with 45 cm inter-rows on soybean grain capacity was

established. These sowing methods provided the highest yields in combination with the seeding rate of 0.7 million items/ha [22]. The studies [23, 24] have shown the equal effect of wide-row sowing methods with interrows of 45 and 60 cm, as well as sowing with a combined width of inter-rows 45×15 cm on the level of soybean grain productivity, while the expansion of inter-rows up to 70 cm has led to its reduction by 0, 20–0.21 t/ha.

In the USA, there are various methods of soybean sowing – from row sowing with 15 cm inter-rows to wide-row sowing with inter-rows up to 90–100 cm. The choice of sowing method depends on weather conditions, soil fertility, maturity group, protection system, etc. In the system of early soybean production, which is practiced in some regions of the United States, on fertile soils, the highest yields of soybeans were obtained on variants with inter-rows from 15 to 40 cm [25–28]. Medium-ripe varieties of soybeans are sown on fertile soils with inter-rows of 50–70 cm, on poor soils – with inter-rows 70–90 cm. When growing late-ripening varieties, the rows are expanded to 90–100 cm [29].

Scientist's opinions also differ as to the influence of the nutrition area and its shape on the quality of soybean grain. Some of them state that with increasing competition between plants, the protein content in grain decreases, and oil content – increases [30], others, on the contrary – note the tendency of increasing the protein content and decreasing the oil content in the thickened crops [31]. It was found in the researches [32] that with increasing seed sowing rate from 300 to 700 thousand items/ha, the content of raw protein and oil in soybean grain decreased by 2.0 and 5.1 %, correspondingly, but due to higher crop grain capacity, the harvest of raw protein and oil from 1 ha was higher.

Thus, the existing opinions of scientists as to the impact of spatial and quantitative placement of plants on the nutrition area on the soybean grain capacity and quality of grain are quite contradictory and indicate the lack of a unified approach to the optimum parameters of crops distribution on the area of nutrition**.** They do not allow to fully draw conclusions about the advantages and disadvantages of quantitative and spatial placement of plants on the nutrition area. Most of the studies in this direction were not conducted in a complex, they were carried out on obsolete cultivars that differ in morpho-biotype from modern ones and, accordingly, have their optimum parameters of plant distribution on the area. Therefore, these results cannot be extended to new soybean cultivars, as they will not provide optimum conditions for crop growth and development.

The purpose and tasks of the study. The purpose of the study is to substantiate the elements of soybean cultivation technology that would ensure high crop capacity and grain quality. To achieve this goal, the following tasks were identified:

– to determine the grain capacity of soybean cultivars depending on the seed sowing rate, inter-rows width and weather conditions;

– to establish the influence of elements of soybean growing technology on protein content in grain and its harvesting from 1 ha;

– to study the influence of different variants of combining seed sowing rate and inter-rows width on the oil content in soybean grain and its harvesting from 1 ha.

Conditions and methods of research. The research was being carried out in the Left-Bank Forest-Steppe of Ukraine during 2015–2019. Multifactor experiments were performed by the method of split sites in four replications according to the generally accepted methods [33]. Areas of the first order were represented by two cultivars of soybean of different maturity groups – ultra-early maturing cultivar Annushka and early-maturing cultivar Bajka (factor *A*), the second order – three variants of inter-rows width: 15, 45 and 70 cm (factor *B*), the third order – five variants of the seed sowing rate: 0.8; 0.9; 1.0; 1.1 and 1.2 million items/ha (factor *C*). The area of the sowing plot is 35 m^2, the accounting area is 15 m^2. The seed sowing rate of 0.8 million items/ha was taken as a control. The protein content was determined

according to the nuclear magnetic resonance (NMR) 4117: 2007 [34]. The determination of oil content in the seeds of the studied samples was performed in the laboratory using pulsed nuclear magnetic resonance (NMR) DSTU ISO 10565: 2003 [35]. The calculation of oil harvesting per hectare of sowing was performed according to the recommended edition [36].

The analysis of the experimental data was carried out by methods of variation statistics, regression and disperse analysis using the Microsoft Office Excel 2010 application package.

Hydrothermal conditions during the research years differed significantly from long-term indicators, which allowed a more complete study of the influence of the studied factors and the identification of the optimum ratios of their variants.

In 2015, the amount of precipitation during the vegetation period exceeded the average long-term indicators, but the distribution was very uneven. In particular, the total amount of precipitation in May was actually at the same level as the average long-term ones, but the main amount (about 30 mm) fell at the beginning of the first decade of May. Therefore, during the most important periods of soybean plant development, when crops suffer more from the lack of moisture, there was a shortage of precipitation. A similar trend was observed in June.

This year the air temperature during the growing season of soybean crops exceeded the average long-term indicators, but did not exceed the limits allowed for soybean crops. The excess was the largest in the third decade of April and May – by 2.7 and 4.8 °C, correspondingly, as well as in the first and second decades of June – by 3.5 and 3.9 °C.

The growth and development of soybean crops took place at low air temperatures at the initial stages of growth and excessive rainfall throughout the growing season in 2016. The amount of precipitation exceeded the climatic norm by 143 % (SCC – 1.38).

The hydrothermal conditions of 2017 year, except April, can be described as arid (rainfall during the growing season was by 59 % less than normal). The temperature indicators were higher than the average long-term ones, but did not exceed the biologically acceptable for soybean crops.

The weather conditions of 2018 were characterized by the deficiency of precipitation, their uneven distribution and high temperatures. The average temperature during the soybean growing season was by 3.4 °C higher than the climatic norm. During the first decade of May, the precipitation was twice higher than the norm when the temperature was 23.2 °C, which exceeded the average long-term indicator by 10.0 °C.

In 2019, there was also a significant shortage of moisture by the temperature indicators at the level of climatic norm. During the growing season, the quatity of rainfall was twice less than the average long-term indicators, in addition, most of them fell during the first half of the growing season of soybean crops.

Thus, weather conditions during the years of research by the temperature regime, the amount and distribution of precipitation differed significantly from the average long-term indicators. However, taking into account the trend of global warming, it should be noted that they were typical for the area. Generally, the biological conditions of soybean crops were more in line with the weather conditions of the growing season of 2015 and 2016. The worse conditions for crops occurred during 2017–2019.

Results and Discussion

***Grain capacity of soybean cultivars belonging to different maturity groups under a complex influence of seed sowing rate, inter-rows width and weather conditions*.** The crop grain capacity of both soybean cultivars underwent significant changes depending on the studied elements of cultivation technology and weather conditions. On the average, it was the highest in row crops of soybean cultivar Bajka with a sowing rate of 1.0 million items/ha – 2.18. During the years of research, the highest crop grain capacity was peculiar for row crops of this cultivar, but at different sowing rates. Thus, the highest soybean

grain capacity of this cultivar in 2015 and 2019 was at the sowing rate of 1.1 million items/ha – 2.33 and 1.76 t/ha, in 2016 – at the sowing rate of 1.0 million items/ha – 4.12 t/ha, and during the least favourable 2017 and 2018 – under the highest studied seeding rate of 1.2 million items/ha – 2.00 and 1.30 t/ha, accordingly (table 1).

Table 1: Soybean grain capacity depending on different combinations of seeding rates with inter-rows width, t/ha

Inter-row width, cm (factor *B*)	Rate of seeding, million seeds/ha (factor *C*)	Year					Average
		2015	2016	2017	2018	2019	
15	0.8	1.95/1.53	2.83/1.97	1.44/1.25	1.07/0.90	1.39/1.20	1.74/1.37
	0.9	2.14/1.66	3.79/2.21	1.58/1.30	1.10/1.00	1.56/1.34	2.03/1.50
	1.0	2.23/1.77	4.12/2.35	1.69/1.41	1.23/1.08	1.65/1.46	2.18/1.61
	1.1	2.33/1.84	3.57/2.45	1.79/1.62	1.25/1.15	1.76/1.59	2.14/1.73
	1.2	1.86/2.05	2.20/2.49	2.00/1.73	1.30/1.27	1.70/1.71	1.81/1.85
45	0.8 (*k*)	1.78/1.54	2.58/1.70	1.18/1.03	0.96/0.83	1.34/1.15	1.57/1.25
	0.9	1.90/1.62	3.52/1.77	1.29/1.11	1.07/0.89	1.44/1.25	1.84/1.33
	1.0	2.00/1.79	2.68/1.80	1.40/1.32	1.16/1.08	1.49/1.36	1.75/1.47
	1.1	1.80/2.03	2.21/1.95	1.49/1.44	1.25/1.05	1.47/1.50	1.64/1.59
	1.2	1.70/1.85	1.83/1.73	1.59/1.51	1.24/1.18	1.39/1.51	1.55/1.56
70	0.8	1.24/1.00	2.02/1.12	1.03/0.98	0.88/0.78	1.19/1.08	1.27/0.99
	0.9	1.52/1.05	1.96/1.37	1.06/1.17	0.92/0.85	1.31/1.15	1.35/1.12
	1.0	1.39/1.30	1.62/1.53	1.17/1.33	0.95/0.96	1.24/1.21	1.27/1.27
	1.1	1.31/1.23	1.57/0.91	1.32/1.43	1.11/0.99	1.15/1.20	1.29/1.15
	1.2	1.04/1.11	1.45/0.89	1.11/1.31	0.98/1.06	1.09/1.14	1.13/1.10
Average by factor *B*	15	1.94	2.80	1.58	1.14	1.53	1.80
	45 (*k*)	1.80	2.18	1.34	1.07	1.39	1.56
	70	1.22	1.44	1.19	0.95	1.18	1.20
Average by factor *C*	0,8 (*k*)	1.51	2.04	1.15	0.90	1.23	1.37
	0.9	1.65	2.44	1.25	0.97	1.34	1.53
	1.0	1.75	2.35	1.39	1.08	1.40	1.59
	1.1	1.76	2.11	1.52	1.13	1.45	1.59
	1.2	1.60	1.77	1.54	1.17	1.42	1.50
Average by cultivars	Bajka	1.75	2.53	1.41	1.10	1.41	1.64
	Annushka	1.56	1.75	1.33	1.01	1.31	1.39
Average		1.66	2.14	1.37	1.05	1.37	1.52
LED_{05} of effect *A*		0.05	0.10	0.04	0.02	0.07	–
LED_{05} of effect *B*		0.06	0.12	0.05	0.03	0.10	–
LED_{05} of effect *C*		0.08	0.15	0.06	0.04	0.12	–
LED_{05} of interaction *ABC*		0.19	0.37	0.15	0.09	0.23	–

Note: the numerator shows soybeans grain capacity of the cultivar Bajka, the denominator – the cultivar Annushka (control).

On the average by years, cultivars and variants of inter-rows width, the highest soybean grain capacity was formed at the sowing rate of 1.0 million items/ha – 1.59 t/ha. It increased to a greater extent with the augmentation in the sowing rate from 0.8 to 0.9 million items/ha – by 0.16 t/ha. With its increase from 0.9 to 1.0 million items/ha, the crop capacity increased only by 0.06 t/ha, and further increase in the sowing rate led to its decrease.

The influence of seeding rate on crop grain capacity of both soybean cultivars largely depended on the width between rows. Particularly, in the cultivar Bajka the highest grain capacity on the average over the years on variants with inter-row width of 15 cm was at the sowing rate of 1.0 million items/ha – 2.18 t/ha, and on variants with inter-rows width of 45 and 70 cm accordingly at the sowing rate of 0.9 million items/ha – 1.84 and 1.35 t/ha, correspondingly. At the same time, on wide-row crops with 70 cm width of inter-rows, the grain capacity of this cultivar with the increased rate of sowing from 0.8 to 0.9 million items/ha has enlarged only by 0.08 t/ha that does not exceed LED_{05}, so the optimum sowing rate of Bajka seeds for these inter-rows is 0.8 million items/ha.

In Annushka soybean, the highest crop grain capacity on the studied variants of interrows width was also at different sowing rates. It is important to underline that in all variants of inter-rows, the highest crop grain capacity of this cultivar was formed at a higher seeding rate than in the cultivar of soybean Bajka. It is natural, because this cultivar is characterized by less ability to branching. On the average over the years on row crops, its highest crop capacity – 1.85 t/ha, was at the highest sowing rate – 1.2 million items/ha. On wide-row crops with inter-rows of 45 and 70 cm, the highest crop grain capacity – 1.59 and 1.27 t/ha was observed on variants with a seeding rate of 1.1 and 1.0 million items/ha, correspondingly. Based on the obtained data, it can be stated that with different sowing methods the optimum seeding rate for Annushka soybean is by 0.1–0.2 million items/ha higher than for Bajka soybean cultivar.

Soybean is a crop that is very demanding for hydrothermal growing conditions [1]. Since the historical place of soybeans origin is regions with a warm monsoon climate, the temperature regime for it is an important condition for the formation of high yields. In addition to the sum of active temperatures, moisture is an important factor in obtaining crop high yields.

The influence of seed sowing rate on crop grain capacity of both soybean cultivars largely depended on weather conditions. In more favourable weather conditions of the growing season, the highest soybean grain capacity was formed at a lower seeding rate. To a greater extent, this trend was observed in soybean cultivar Bajka. Particularly, in favourable 2016, on row crops of this cultivar it was the highest at seed sowing rates of 1.0 million items/ha – 4.12 t/ha, while in less favourable 2017 and 2018 at sowing rate of 1.2 million items/ha it was 2.00 and 1.30 t/ha. On wide-row crops with inter-rows of 45 cm, the highest crop capacity of this cultivar in more favourable weather conditions of the growing season of 2015 and 2016 was formed on the variants with sowing rate of 1.0 and 0.9 million items/ha – 1.90 and 3.52 t/ha, correspondingly, while in less favourable weather conditions in 2017 and 2018 – with sowing rates of 1.2 and 1.1 million items/ha – 1.59 and 1.25 t/ha, correspondingly.

Thus, the yield volume at the optimum seed sowing rate is not a simple sum of the results of growth and development of separate crops, but it is formed in the process of their complex interaction as a holistic productive system of agrophytocoenosis. It is important to ensure such rate of seed sowing under which non-highest productivity of one crop is achieved but receiving great yield of the main production of high quality

with minimum labour expenditures. Both excessive thickening and thinning lead to lower crop capacity.

The analysis of the influence of the studied variants of inter-rows width on soybean grain capacity showed the advantage of variants with 15 cm inter-rows. On the average by years, cultivars and sowing rates, soybean grain capacity on these variants was by 0.24 t/ha (15.4 %) and 0.60 t/ha (50.0 %) higher than on the variants with the inter-rows of 45 and 70 cm, correspondingly.

Our studies are coordinated with the results received by other authors. Researchers Jason L Debrui and Palle Pedersen [37] studying different sowing rates and the width of soybean inter-rows have found that higher soybean crop capacity is formed on row crops with a sowing rate of 124 kg/ha. This point of view is supported by other scientists, who state that soybean crop capacity is reduced on wide-row crops [38–40]. Other authors have also identified the advantage of narrow-row soybean sowing. They have found that in the northern and southern regions of the United States, the advantage in grain capacity of crops with narrower inter-rows became greater with a reduction of the growing season of crops due to biological characteristics of the cultivar, sowing terms and weather conditions [41].

The advantage in crop grain capacity among the studied cultivars during all years for all variants of inter-row width and seed sowing rate was the soybean cultivar Bajka. It was larger in more favourable weather conditions of the growing season. Thus, in 2015 and 2016, the crop grain capacity of this cultivar was by 0.19 and 0.78 t/ha, higher than in Annushka cultivar , while in less favourable 2017, 2018 and 2019 – by 0.08, 0.09 and 0.10 t/ha.

In the conducted researches the soybean grain capacity underwent the greatest changes under the influence of weather conditions of the year of cultivation. In particular, the maximum difference between crop grain capacity under the influence of this factor was equal to 1.09 t/ha (comparing with 1.05 t/ha in 2018 to 2.14 t/ha in 2016), while under the influence of sowing method, cultivar characteristics and sowing rates – 0.60 t/ha, 0.25 and 0.22 t/ha, correspondingly.

The influence of elements of soybean growing technology on grain protein content. Taking into account the importance of the quality of soybean production, namely the content of protein and oil in grain, we have determined the effect of different combinations of sowing method and seeding rate on these indicators for both soybean cultivars.

With the expansion of inter-rows, the protein content in grain of both soybean cultivars increased. At the same time, the difference between the protein content for different variants of inter-row was low. On the average over the years, it was only 0.4 % (40.4 % – on variants with inter-rows of 15 cm and 40.8 % – with inter-rows of 70 cm). Over the years of research, a similar regularity was observed. Thus, in 2015, 2016, 2017, 2018 and 2019, the largest difference in protein content in soybean grain depending on the width between rows was 0.3 %, 0.4, 0.3, 0.3 and 0.5 %, correspondingly (table 2).

Table 2: The protein content in soybean grain depending on the studied variants of combining the seed sowing rate with the width between rows, %

Inter-rows width, cm (factor *B*)	Rate of seeding, million seeds/ha (factor *C*)	Year					Average
		2015	2016	2017	2018	2019	
15	0.8	39.3/40.1	39.0/39.8	39.8/40.6	40.1/40.9	39.6/40.4	39.6/40.4
	0.9	39.5/40.3	39.1/40.0	39.9/40.7	40.3/41.1	39.6/40.7	39.7/40.6
	1.0	39.6/40.7	39.3/40.3	40.1/41.1	40.5/41.5	39.9/40.9	39.9/40.9

	1.1	39.9/40.9	39.5/40.6	40.4/41.4	40.8/41.8	39.9/41.1	40.1/41.2
	1.2	40.0/41.2	39.7/40.9	40.6/41.8	41.0/42.1	40.4/41.6	40.3/41.5
45	0.8 (*k*)	39.5/40.4	39.2/40.1	40.0/40.9	40.3/41.2	40.0/40.6	39.8/40.6
	0.9	39.6/40.5	39.4/40.3	40.2/41.2	40.3/41.5	40.0/40.9	40.0/40.9
	1.0	39.8/41.1	39.6/40.7	40.4/41.5	40.8/41.8	40.1/41.4	40.1/41.3
	1.1	39.9/41.3	39.7/40.9	40.5/41.6	40.9/42.0	40.5/41.6	40.3/41.5
	1.2	40.1/41.5	39.9/41.1	40.7/41.9	41.1/42.3	40.5/42.0	40.5/41.8
70	0.8	39.4/40.6	39.1/40.3	39.9/41.1	40.2/41.3	40.0/40.9	39.7/40.8
	0.9	39.5/40.8	39.3/40.6	40.1/41.3	40.5/41.7	40.3/41.1	39.9/41.1
	1.0	39.8/41.1	39.4/40.8	40.2/41.5	40.7/41.9	40.3/41.6	40.1/41.4
	1.1	39.9/41.4	39.7/41.0	40.6/41.8	41.0/42.2	40.4/41.4	40.3/41.6
	1.2	40.4/41.7	40.0/41.3	40.8/42.1	41.2/42.4	40.7/42.0	40.6/41.9
Average by factor *B*	15	40.2	39.8	40.6	41.0	40.4	40.4
	45 (*k*)	40.4	40.1	40.9	41.3	40.8	40.7
	70	40.5	40.2	40.9	41.3	40.9	40.8
Average by factor *C*	0.8 (*k*)	39.9	39.6	40.4	40.7	40.3	40.2
	0.9	40.0	39.8	40.6	41.0	40.4	40.4
	1.0	40.4	40.0	40.8	41.2	40.7	40.6
	1.1	40.6	40.2	41.1	41.5	40.8	40.8
	1.2	40.8	40.5	41.3	41.7	41.2	41.1
Average by cultivars	Bajka	39.8	39.5	40.3	40.7	40.1	40.1
	Annushka	40.9	40.6	41.4	41.7	41.2	41.1
Average		40.3	40.0	40.8	41.2	40.7	40.6

Note: the numerator shows the protein content in grain of the soybean cultivar Bajka, in the denominator – the cultivar Annushka (control).

Under the influence of seed sowing rate, the protein content in soybean grain underwent greater changes than under the influence of the studied variants of inter-rows width. On the average over the years, the largest difference between the protein content in grain under the influence of this factor averaged over the years, cultivars and methods of sowing was 0.9 %. There was a close direct relationship between the protein content in grain and the sowing rate, because with the increase of the sowing rate of seeds by a constant indicator – 0.1 million items/ha, the protein content in grain increased by 0.2–0.3 %.

The effect of seed seeding rate on the changeability of indicators of protein content in grain was greater in soybean cultivar Annushka. This trend was noticed during all years. Particularly, in 2015, 2016, 2017, 2018 and 2019, with the increase of the sowing rate from 0.8 to 1.2 million items/ha, the protein content in grain of soybean cultivars Bajka and Annushka increased by sowing methods on the average by 0, 8 and 1.1 % accordingly.

The analysis of the obtained results shows that in years with different weather conditions, under various variants of competition between plants, higher indicators of protein content were peculiar for the soybean cultivar Annushka. During all years, on the average, according to the studied variants of inter-rows width and seed sowing rates, the protein content in soybeans of this cultivar was by 1.0–1.1 % higher than in soybeans of Bajka variety.

While conducting the regression analysis, the average inverse connection between the protein content in Annushka soybean grain and the amount of precipitation during vegetation was determined – r = –0.43, which is described by the following equation regression dependence: $y = –25{,}729x + 1116.4$ (Fig. 1).

Between the protein content in the soybean grain of Bajka cultivar and the amount of precipitation during the interphase period of fruitforming-ripening, the average inverse connection was also established – $r = –0.60$, that is characterized by the following equation regression dependence: $y = –37.617x + 1577.9$.

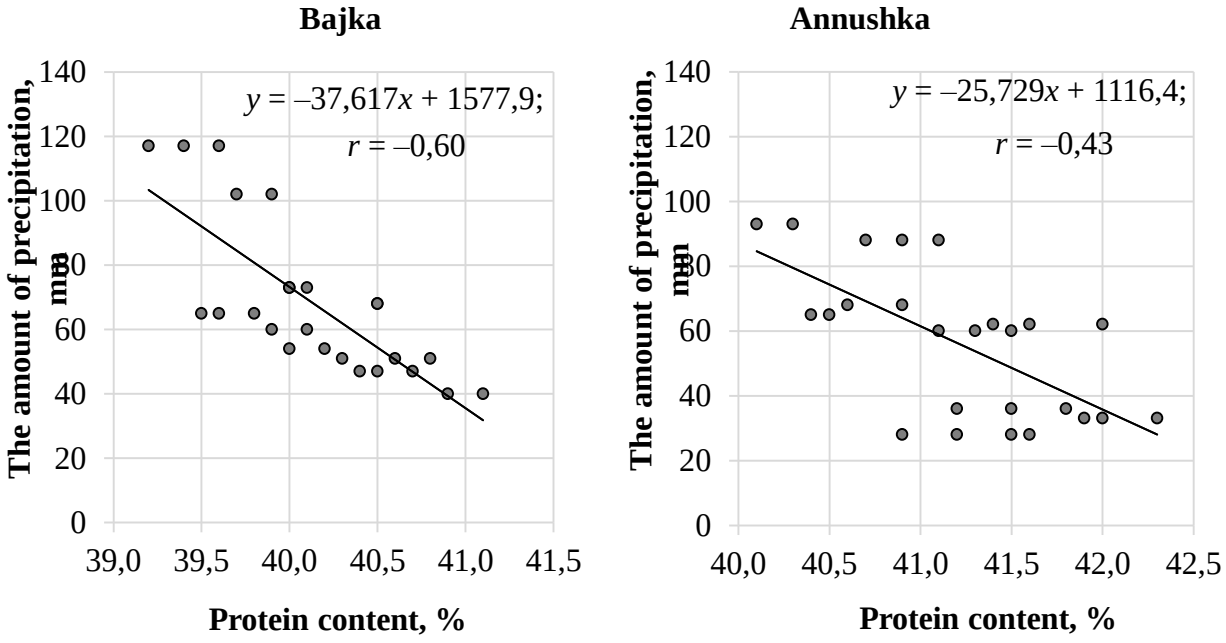

Fig. 1. The correlation between the protein content in soybean grain of the studied cultivars and the amount of precipitation during the interphase period of fruitforming-ripening

Since soybeans are grown primarily for protein and oil, it is important to determine their harvesting from the unit of area, which will allow a more objective comparison of the effectiveness of the studied variants, as there are frequent cases when a certain variant outstarts others, but due to worse indicators of grain quality, its advantage can be levelled and, by harvesting protein and oil, it can show worse result comparing with others.

In the conducted researches the greatest protein harvest was observed on row crops with inter-row width of 15 cm. On the average by years, cultivars and seed sowing rates it comprised 636 kg/ha, while on wide-row crops with inter-rows width of 45 and 70 cm – 558 and 432 kg/ha, correspondingly (Table 3).

The higher protein harvesting on the variants with inter-rows width of 15 cm was obtained primarily due to the significantly higher crop grain capacity, as the protein content in grain on these variants was the lowest. That is why, under the influence of the studied variants of inter-rows width, the discrepancy between the indicators of protein harvesting is smaller than between crop grain capacity.

Table 3: Harvesting of protein from 1 ha of soybean crops depending on the studied variants of combining of the seeding rate and the width of inter-rows, kg

Inter-rows width, cm (factor *B*)	Rate of seeding, million seeds/ha (factor *C*)	Year					Average
		2015	2016	2017	2018	2019	
15	0.8	659/528	949/674	493/436	369/317	550/485	604/488
	0.9	727/575	1274/760	542/455	381/353	618/545	708/538
	1.0	759/620	1392/814	583/498	429/386	658/597	764/583
	1.1	800/647	1213/855	622/577	439/413	702/653	755/629
	1.2	640/726	751/876	698/622	458/460	687/711	647/679
45	0.8 (*k*)	605/535	870/586	406/362	333/294	536/467	550/449
	0.9	647/564	1193/613	446/393	374/318	576/511	647/480
	1.0	685/633	913/630	486/471	407/388	597/563	618/537
	1.1	618/721	755/686	519/515	440/379	595/624	585/585
	1.2	586/660	628/611	557/544	438/429	562/634	554/576
70	0.8	420/349	679/388	353/346	304/277	476/442	446/360
	0.9	516/368	662/478	366/416	320/305	528/473	478/408
	1.0	476/459	549/537	404/475	332/346	500/503	452/464
	1.1	450/438	536/321	461/514	391/359	465/497	461/426
	1.2	361/398	499/316	389/474	347/386	443/479	408/411
Average by factor *B*	15	668	956	533	400	621	636
	45 (*k*)	625	748	470	380	567	558
	70	424	497	420	337	481	432
Average by factor *C*	0.8 (*k*)	516	691	400	316	493	483
	0.9	566	830	436	342	542	543
	1.0	605	806	486	381	570	570
	1.1	612	728	535	404	589	574
	1.2	562	614	547	420	586	546
Average by cultivars	Bajka	597	858	488	384	566	579
	Annushka	548	610	473	361	546	508
Average		572	734	481	372	556	543

Note: the numerator shows the harvest of protein from 1 ha of soybean cultivars Bajka, the denominator – Annushka cultivar (control).

With increasing the seed sowing rate from 0.8 to 1.0 million items/ha, crop grain capacity and protein content increased, so the difference in protein harvesting between these variants on the average by years, cultivars and methods of sowing was higher than the crop capacity and protein content in grain. In particular, as to the protein harvest it was 18.5 %, while as for crop grain capacity and protein content in it – 17.1 and 1.3 % correspondingly.

The comparison of protein harvest indicators showed a significant advantage of the Bajka cultivar, despite the fact that the protein content in grain of this cultivar was lower than in the Annushka cultivar. Thus, the protein harvest of the Bajka cultivar averaged 579 kg/ha by years, sowing methods and seeding rates, which is by

14.0 % higher than that of the Annushka soybean. The significantly higher harvest of the Bajka soy protein was primarily due to crop grain capacity, which was by 18.0 % higher.

The weather conditions of the year had the greatest influence on protein harvest. Thus, the largest difference between these indicators under the influence of weather conditions was 362 kg/ha, while under the influence of the studied variants of inter-rows, seeding rates and cultivar characteristics – 204 kg/ha, 91 and 71 kg/ha.

As well as crop grain capacity, protein harvest was the highest on the average by years on row crops of soybean cultivar Bajka at sowing rates of 1.0 million items/ha – 764 kg/ha. In Annushka soybean the highest protein harvest – 0.679 kg/ha, was also on the variants with the inter-rows width of 15 cm, but at seeding rates of 1.2 million items/ha correspondingly.

On crops with 45 cm inter-rows , the largest harvest of soy protein of the Bajka cultivar, as well as crop grain capacity, was on the variants with sowing rate of 0.9 million items/ha – 647 kg/ha, and on crops of the Annushka cultivar under sowing 1.1 million items/ha – 585 kg/ha.

The influence of seed sowing rate on oil content in soybean grain. Unlike the protein content in grain, the oil content in grain of both soybean cultivars decreased with increasing sowing rate and expansion of inter-rows. Thus, on the average over the years, with the increase in seed sowing rate from 0.8 to 1.2 million items/ha, the oil content in soybean grain on the average by cultivars and studied variants of inter-rows width decreased from 20.8 to 20.2 % (Table 4).

Among the investigated factors, the sowing rate had a greater influence on the variability of soybean oil content indicators. The observed regularity was more revealed in the soybean cultivar Annushka. Thus, the largest difference in the oil content in grain of this cultivar, depending on the sowing rate on the average over the years and methods of sowing was – 0.7 %, while under the influence of the method of sowing – 0.3 %.

The oil content in grain underwent the greatest changes depending on the cultivar characteristics. The Bajka cultivar had higher oil content in grain in the context of all variants of combinations of inter-row width and seed sowing rate, which corresponds to its cultivar characteristics. On the average, over the years, by inter-rows width and seed sowing rates, the oil content in grain of this cultivar was by 2.7 % higher than in the Annushka cultivar.

Table 4: The oil content in soybean grain, depending on the studied variants of combining the seeding rate and the width between rows, %

Inter-rows width, cm (factor *B*)	Rate of seeding, million seeds/ha (factor *C*)	Year					Average
		2015	2016	2017	2018	2019	
15	0.8	22.7/19.9	23.0/21.0	22.2/19.0	21.8/18.8	22.4/19.5	22.4/19.6
	0.9	22.5/19.6	22.9/20.8	22.1/18.9	21.6/18.6	22.4/19.7	22.3/19.5
	1.0	22.2/19.5	22.6/20.7	21.8/18.8	21.5/18.5	21.9/19.3	22.0/19.4
	1.1	22.1/19.4	22.5/20.5	21.7/18.6	21.3/18.3	21.9/19.0	21.9/19.2
	1.2	22.0/19.2	22.4/20.4	21.6/18.5	21.2/18.1	21.6/19.0	21.8/19.0
45	0.8 (*k*)	22.5/19.8	22.8/20.9	22.0/18.9	21.6/18.6	22.5/19.4	22.3/19.5
	0.9	22.4/19.5	22.6/20.6	21.8/18.7	21.4/18.5	22.3/19.2	22.1/19.3
	1.0	22.3/19.4	22.5/20.5	21.7/18.6	21.2/18.3	22.3/19.2	22.0/19.2
	1.1	22.0/19.3	22.4/20.4	21.6/18.5	21.1/18.1	22.0/19.0	21.8/19.1
	1.2	21.8/19.1	22.2/20.1	21.4/18.3	21.0/17.9	21.6/18.8	21.6/18.8
70	0.8	22.2/19.7	22.5/20.8	21.7/18.8	21.3/18.5	22.0/19.0	21.9/19.4

	0.9	22.1/19.6	22.3/20.7	21.5/18.7	21.2/18.3	21.8/19.0	21.8/19.3
	1.0	21.7/19.4	22.1/20.5	21.3/18.6	21.0/18.2	21.8/18.7	21.6/19.1
	1.1	21.6/19.2	22.0/20.2	21.2/18.4	20.9/18.0	21.5/18.7	21.4/18.9
	1.2	21.5/18.9	21.9/19.9	21.1/18.1	20.7/17.9	21.3/18.3	21.3/18.6
Average by factor *B*	15	20.9	21.7	20.3	20.0	20.7	20.7
	45 (*k*)	20.8	21.5	20.2	19.8	20.6	20.6
	70	20.6	21.3	19.9	19.6	20.2	20.3
Average by factor *C*	0.8 (*k*)	21.1	21.8	20.4	20.1	20.8	20.8
	0.9	21.0	21.7	20.3	19.9	20.7	20.7
	1.0	20.8	21.5	20.1	19.8	20.5	20.5
	1.1	20.6	21.3	20.0	19.6	20.4	20.4
	1.2	20.4	21.2	19.8	19.5	20.1	20.2
Average by cultivars	Bajka	22.1	22.4	21.6	21.3	22.0	21.9
	Annushka	19.4	20.5	18.6	18.3	19.1	19.2
Average		20.8	21.5	20.1	19.8	20.5	20.5

Note: the numerator shows the oil content in the soybeans of the Bajka cultivar, the denominator shows the Annushka cultivar (control).

The influence of cultivar characteristics increased in less favourable weather conditions of vegetation, that were in 2017 and 2018. Thus, the oil content in grain of soybean cultivar Bajka on the average by sowing methods and seeding rates during these years was by 3.0 % higher than in the cultivar Annushka, while in the most favourable weather conditions in 2016 – only by 1.9 %.

Weather conditions of vegetation had a greater influence on the variability of oil content in soybean grain than the studied variants of inter-row width and seeding rates. Thus, the largest difference between the indicators of oil content in grain under the influence of weather conditions was 1.7 %, while under the influence of inter-rows width and seeding rate, it did not exceed 1.0 %.

It is worth noting the different regularities of weather conditions influence on the protein and oil content of soybean crops. Particularly, the protein content in grain was higher in dry years with higher temperatures, while the oil content – in years with more rainfall during the growing season and lower temperatures.

It is important to mark a similar regularity of influence of the studied technological factors on the oil content in soybean by years of research, namely: the highest oil content in soybean grain of both cultivars was formed on variants with inter-rows width of 15 cm and seed sowing rate – 0.8 million items/ha. In addition, the strength of these factors influence was also equivalent, i.e. with increasing seed sowing rate and expansion of inter-rows width, the oil content in grain of both soybean cultivars decreased by an equal indicator.

On the basis of correlation analysis, the strength and direction of the relationship between the oil content in soybean and the amount of precipitation during the interphase period of fruiting-forming and ripening were determined.

The oil content in grain of soybean cultivars Annushka and Bajka has a strong direct relationship with the amount of precipitation – r = 0.93 and r = 0.76, correspondingly, which is described by the following regression equations – y = 86,429x – 1510.4 and y = 104.13x – 2105.4 (Fig. 2).

Bajka **Annushka**

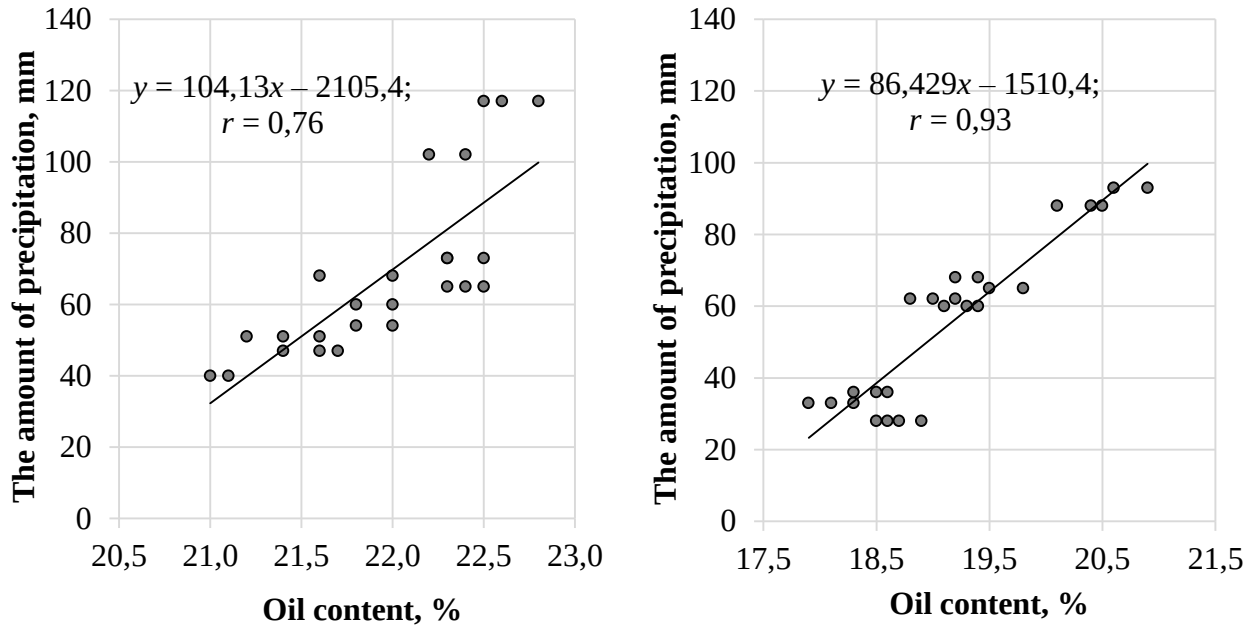

Fig. 2. The dependence between the oil content in soybean grain of the studied cultivars and the amount of precipitation during the interphase period of fruitingforming and ripening

It is not correct to draw conclusions about the effectiveness of the compared variants of cultivation technology by indicators of oil content, as well as by protein content, because the main goal is to increase their gross production. Therefore, only the indicators of oil harvest can show the advantage of one or another variant. Moreover, it is believed that harvesting the oil from a hectare of soybean is determined primarily by crop capacity and not by the oil content in grain [42, 43].

Crop grain capacity and oil content were the highest on the variants with inter-rows width of 15 cm, and the lowest – with inter-rows of 70 cm, so it is logical that the largest difference in the impact of the studied variants of inter-rows width was by the indicators of oil harvest from a hectare. In particular, by crop grain capacity and oil content in grain on the average by other factors it was 55.0 and 1.5 %, while by oil harvest from a hectare – 60.0 % (Table 5). This trend has been observed during all years.

Table 5: Harvest of oil from 1 ha of soybean crops depending on the studied variants of combining the seed sowing rate with the width between rows, kg

Inter-rows width, cm (factor *B*)	Rate of seeding, million seeds/ha (factor *C*)	Year					Average
		2015	2016	2017	2018	2019	
15	0.8	381/262	560/356	275/204	201/146	311/234	346/240
	0.9	414/280	746/395	300/211	204/160	348/264	402/262
	1.0	426/297	801/418	317/228	227/172	363/282	427/279
	1.1	443/307	691/432	334/259	229/181	385/302	416/296
	1.2	352/338	424/437	372/275	237/198	371/325	351/315
45	0.8 (*k*)	344/262	506/306	223/167	178/133	299/223	310/218
	0.9	366/272	684/314	242/179	197/142	318/240	361/229
	1.0	384/299	519/317	261/211	211/170	328/261	341/252
	1.1	341/337	426/342	277/229	227/163	321/285	318/271

	1.2	319/304	349/299	293/238	224/182	300/284	297/261
70	0.8	237/169	391/200	192/158	161/124	261/205	248/171
	0.9	289/177	376/244	196/188	168/134	286/219	263/192
	1.0	259/217	308/270	214/213	172/150	268/226	244/215
	1.1	243/203	297/158	241/226	199/153	246/224	245/193
	1.2	192/180	273/152	201/204	174/163	232/209	214/182
Average by factor *B*	15	350	526	278	195	319	334
	45 (*k*)	323	406	232	183	286	286
	70	217	267	203	160	238	217
Average by factor *C*	0.8 (*k*)	276	386	203	157	256	256
	0.9	300	460	219	167	279	285
	1.0	314	439	241	184	288	293
	1.1	312	391	261	192	294	290
	1.2	281	322	264	196	287	270
Average by cultivars	Bajka	333	490	263	201	309	319
	Annushka	260	309	213	158	252	238
Average		296	400	238	179	281	279

Note: the numerator shows the harvest of oil from 1 ha of soybean crops of the Bajka cultivar, the denominator shows the Annushka cultivar (control).

As well as sowing methods, sowing rates had a significant effect on oil harvest from a unit of area in the studied range. Oil collection increased mostly with its increase from 0.8 to 0.9 million items/ha – by 11.3 %, further increase of the sowing rate to 1.0 million items/ha provided the increase in oil harvest by only 2.8 %. With the increase of the seed sowing rate from 1.0 to 1.1 million items/ha, there was a slight decrease in oil harvest by – 1.0 %, and with its further increase to 1.2 million items/ha, oil harvest decreased by more than 7.0 %, both due to a significant reduction in crop capacity and reduction of oil content in grain.

The effect of sowing rate was higher on variants with inter-rows width of 15 cm. Thus, the largest difference between oil harvest depending on the sowing rate of the cultivar Bajka on variants with inter-rows width of 15 cm was 81 kg/ha, and with the width of 45 and 70 cm – 64 and 49 kg/ha, correspondingly. As for Annushka soybean, the largest difference between the oil harvest rates depending on the seeding rate on the variants with inter-rows width of 15, 45 and 70 cm was 75 kg/ha, 53 and 44 kg/ha, correspondingly.

Under different inter-row variants, the largest oil harvest from a hectare of soybean crops of both cultivars, as well as their crop capacity, was at different sowing rates. It was the largest on the same variants where they got the highest yields. Thus, the highest harvest of Bajka cultivar oil on the average over the years on row crops – 427 kg/ha was on the variants with a sowing rate of 1.0 million items/ha, and on wide-row crops with inter-rows of 45 and 70 cm – under sowing 0.9 million items/ha – 361 and 263 kg/ha, correspondingly. On variants of Annushka soybean cultivar, the largest oil harvest on row crops – 315 kg/ha was under sowing 1.2 million items/ha, and on wide-row crops with inter- rows of 45 and 70 cm – under sowing 1.1 and 1.0 million items/ha – 271 and 215 kg/ha, accordingly.

The influence of seed sowing rate on the variability of oil harvesting from 1 ha was the highest in 2016, more favourable for soybean crops year. Thus, the largest difference between the rates of oil harvesting from 1 ha under its influence that year was 138 kg/ha (42.9 %), while in 2015, 2017, 2018 and 2019 – 38, 61, 39 and

38 kg/ha, or 13.8 %, 30.0, 24.8 and 14.8 % correspondingly.

Within the years, the highest oil harvest was at different seeding rates. During the years with more favourable weather conditions of vegetation for soybean crops, it was the highest at a lower sowing rate. Particularly, in 2015 and 2016, the largest oil harvest – 314 and 460 kg/ha were obtained on variants under the sowing rates of 1.0 and 0.9 million items/ha, and in less favourable weather conditions of the growing season in 2017, 2018 – under the highest seed sowing rate – 1.2 million items/ha – 264 and 196 kg/ha, correspondingly. At the same time, the oil harvest on these variants was in fact equivalent to that obtained under sowing rates – 1.1 million items/ha. The difference between them did not exceed 2.0 %.

The advantage of Bajka soybean by oil harvest indicators comparing with the Annushka cultivar was much higher than by indicators of crop grain capacity and oil content in grain, because along with the increase of crop grain capacity, the oil content also grew. Particularly, on the average over the years, variants of inter-rows and seed sowing rates, oil harvest from 1 ha of soybean cultivar of Bajka was by 34.0 % higher than that of Annushka, while crop grain capacity and oil content in grain were higher by 18.0 and 14.1 %, correspondingly. The noticed regularity was observed during all years of research.

It is important to note the greater advantage of the Bajka cultivar by indicators of oil harvest in more favourable weather conditions for plant vegetation. Particularly, the oil harvest of this variety in 2015 and 2016 was by 73 and 181 kg/ha (28.1 and 58.6 %) higher than in the Annushka cultivar, while in 2017, 2018 and 2019 – only by 50, 43 and 57 kg/ha (23.5, 27.2 and 22.6 %), correspondingly.

Conclusions

The following conclusions should be drawn from the presented materials:

1. By the indicators of crop grain capacity of both soybean cultivars at all sowing rates, the preference is given to variants with inter-rows width of 15 cm. It is impossible to single out the best sowing rate, because on each variant of inter-rows width, the highest crop grain capacity was obtained at different sowing rates. In particular, on row soybean crops of Annushka and Bajka cultivars, higher grain yields – 1.85 and 2.18 t/ha were obtained at sowing rates – 1.2 and 1.0 million items/ha, correspondingly, with 45 cm width of inter-rows – at sowing 1.1 and 0.9 million items/ha – 1.59 and 1.84 t/ha and with interrows width of 70 cm – at sowing 1.0 and 0.9 million items/ha – 1.27 and 1.35 t/ha.

2. During the whole period of research, the protein content in grain of Annushka soybean on the average by other factors was by 1.0–1.1 % higher than in Bajka cultivar. Thickening of crops by increasing the seeding rate and expanding the inter-rows led to the increase in protein content in grain. The highest protein harvest on the average over the years – 764 kg/ha was observed in the cultivar Bajka on the variants of combining the seeding rate of 1.0 million items / ha with inter-rows width of 15 cm. In the variety Annushka the largest protein harvest – 679 kg/ha was received under the same inter-rows width but at sowing rate of 1.2 million items/ha. On crops with inter-rows of 45 cm width, the largest harvest of soy protein of the Bajka cultivar, was observed at sowing rates of 0.9 million items/ha – 647 kg/ha, and on crops of Annushka cultivar – at sowing 1.1 million items/ha – 585 kg/ha.

3. The oil content in grain of both soybean cultivars decreased with increasing sowing rate and expansion of inter-rows. The Bajka cultivar had a higher oil content in grain in the context of all combinations of inter-rows width and seed sowing rate. On the average over the years, seed sowing rates and inter-rows width of the studied variants, the oil content of Bajka soybean grain was by 2.7 % higher than that of Annushka. The largest oil harvest from 1 ha of both soybean cultivars under all sowing rates was provided by sowing with 15 cm width of inter-rows. Oil harvesting from 1 ha with inter-rows of 15, 45 and 70 cm averaged 334, 286 and 217 kg/ha,

correspondingly. The Bajka soybean cultivar had the highest oil harvest – 427 kg/ha on variants with inter-rows width of 15 cm in combination with the sowing rate of 1.0 million items/ha. As for the Annushka soybean cultivar, it had the largest oil harvest – 315 kg/ha on variants with inter-rows width of 15 cm, but at a higher sowing rate – 1.2 million items/ha.

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