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# Soybean Productivity in the Forest-Steppe of Ukraine under Ecologization of Cultivation Technology

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## ABSTRACT

The scientific article is devoted to the greening of technologies and its individual aspects, which is an important agricultural measure that can curb further decline in soil fertility, stabilize production systems, and reduce dependence on technological factors. Of the entire complex of agrotechnical measures in biologically based soybean cultivation technologies, the lowest material and labor costs are incurred for pre-sowing seed treatment with bacterial preparations and treatment of crops with growth regulators. The effect of biological products – growth regulators is due to their influence on the plant organism at certain stages of organogenesis and is associated with significant changes in the process of metabolism, restructuring of a number of metabolic systems. In the course of experimental studies, a variant with seed treatment with Rizogumin-Plus and two-time treatment of crops with the retardant chlormequat chloride was identified by the manifestation of the studied soybean traits: first – in phase of the 3rd trifoliate leaf, second – in the budding phase. The main objective of the research was to study the patterns of manifestation and formation of productivity elements and yield level of soybean agrophytocenoses depending on varietal composition, pre-sowing treatment of seeds with a bacterial preparation and concentration of retardant. During 2018–2022, a three-factor experiment will be conducted in the Right-Bank Forest-Steppe of Ukraine. The material of the research was soybean varieties of domestic selection – Azimuth and Golubka, which were studied according to the following field experiment scheme: control (no treatment), seed inoculation (treatment of seed with the biological preparation Rizogumin), concentration of retardant (no treatment, 0.5%, 0.75% and 1% solution). The relevance of the research is reinforced by the task of applied research on the topic: «Development of scientific and technological support for improving soil fertility and rational use of bioresources potential» (state registration number: 0124U000444).

**Keywords**: soybean, legumes, fertilization system, pre-sowing seed treatment, retardant concentration, field germination, survivability.

## INTRODUCTION

Ukraine is a leader in the production of pulses in Europe and is one of the world's ten largest producers. In the context of climate change, the territorial transformation of the cultivation of these crops is a prerequisite for the establishment of a new stage in the production of legume seeds, which will contribute to the rational use of hydrothermal resources of the region, increase production volumes, biologization of agriculture, and obtaining high-quality, organic products (Pantsyreva et. al., 2020a; Puvu et al., 2021). Organic seed production is one of the strategic directions for the accelerated development of Ukraine's agricultural sector and the main goal of the European Green Deal, which regulates the transformation of Europe into a climate-neutral continent (Kaletnik and Lutkovska 2020). To do this, it is necessary to focus on the creation of highly productive varieties of different ripeness groups to clarify the zone of sustainable production, optimize the structure of sown areas of leading crops, development and implementation of knowledge-intensive, eco-innovative technologies for their cultivation, development of regulations for the legal regulation of the cultivation of genetically modified varieties in Ukraine, in-depth study of economic problems of production and use of legume seeds for feed purposes (Tkachuk 2021; Pryshliak et al., 2023). The integrated development of crop and livestock production will not only increase the overall level of agricultural production, but will also become one of the prerequisites for sustainable development of rural areas (Kaletnik and Yaropud 2023; Pohrishchuk et al., 2023).

## LITERATURE REVIEW

In world agriculture, legumes cover an area of more than 100 million hectares (Didur et al., 2020). Soybeans (more than 50 million hectares), beans (23 million hectares) and peas (15 million hectares) occupy the largest area among pulses (Mazur et al., 2021a). Legumes are characterized by the highest protein content among agricultural crops (Kaminsky 2013). The grain and green mass of legumes contain 1.5–3 times more protein than cereals, which makes it possible to obtain the highest yield of digestible protein and essential amino acids per hectare of crops (Razanov et al., 2018). It is also important that their proteins are complete in terms of amino acid composition and are much better absorbed by the body than cereal proteins (Petrichenko et al., 2017). Legumes are of great industrial and raw material importance due to their valuable chemical composition (Mazur et al., 2023). Legumes can be used to prevent both protein and amino acid deficiencies, especially lysine (Pantsyreva 2021). In addition to providing valuable food and feed, legumes are crucial for phytoreclamation, phytosanitary soil treatment, and cost reduction in crop production (Didur et al., 2019). An important source of growth in the production of competitive crop production in the system of sustainable agriculture is an increase in the share of legumes in the structure of sown areas, due to their ability to symbiotic fixation (Bakhmat et al., 2023). The introduction of legumes into scientifically based crop rotations can serve as an important factor in the intensification of agriculture, ensuring the rational use of biological and mineral nitrogen, reducing energy costs and improving the environment (Ivanyshyn et al., 2021). The main components of technology that determine the growth of agricultural production efficiency include, selection of varieties, pre-sowing seed treatment and the use of growth regulators for a particular agroclimatic region are of great importance (Okrushko 2022; Tkachuk 2021). Currently, peas are one of the most common legumes (Khaietska et al., 2023). In world agriculture, it is grown on all continents of the globe (Hnatiuk 2019). For European countries, peas are the main pulses grown for food and feed purposes on an area of about 3 million hectares (Zagorulko et al., 2022). Peas have long been the most common legume crop in the Forest-Steppe zone of Ukraine (Didur et al., 2021). However, among legumes, soybeans stand out as a high-protein and high oilseed crop (Kaminsky 2013). In recent years, soybeans have replaced peas in Ukraine and occupy a larger area due to their better adaptability to sharp fluctuations in weather conditions, especially rather uneven distribution of precipitation and unstable soil moisture during the growing season (Honcharuk et al., 2022). Climate change in recent years has resulted in some soybean varieties being severely affected by drought (Mazur et al., 2021b). Therefore, agricultural producers need varieties for different weather conditions (Pantsyreva et al., 2023). One way to increase soybean grain production is to develop and introduce more productive varieties adapted for cultivation in a particular climate zone (Mazur et al., 2021b). Early and medium-early soybean varieties are of the greatest importance for the conditions of the Forest-Steppe of Ukraine (Petrichenkoet al., 2017). Thanks to the fruitful work of breeders, new varieties with a productivity level of 4–5 t/ha have been created (Petrychenko et al., 2020b). The realization of the genetic potential of the above varieties requires the development and application of appropriate modern models of cultivation technologies (Bakhmat et al., 2023). Fertilization is one of the key factors in increasing the productivity of pulses (Ivanyshyn et al, 2021). The main condition for obtaining high yields of proper quality is optimal plant nutrition, which cannot be achieved without the use of fertilizers (Didur et al., 2021). It was found that when studying the interaction of fertilizers, plant protection and the importance of crop rotation in the formation of soybean seed yield growth, the maximum share (37.3%) was due to the effect of mineral fertilizers (Mazur et al., 2021c). At the same time, most researchers agree that nitrogen fertilizers for soybeans should be applied in small doses (up to 30–40 kg/ha of active ingredient) (Khaietska et al., 2023). Some researchers recommend growing soybeans without the use of nitrogen fertilizers when optimal conditions are created for biological fixation of nitrogen from the air (Petrychenko et al., 2020b). The problem of full provision of plants with available forms of macro- and microelements during ontogeny can be solved by using multicomponent, chelated foliar fertilizers, growth stimulants, and pre-sowing seed treatment in the soybean fertilization system (Okrushko 2022; Mazur et al., 2020a). However, it should be remembered that foliar fertilization, growth stimulants and seed treatment do not replace the main application of fertilizers to the soil, but are effective and, in modern conditions, actually a mandatory supplement (Monarkh and Pantsyreva 2019). As the emphasis in agricultural production in recent years has been on ecological and sustainable development using renewable resources, the role of biological nitrogen will increase (Mazur et al., 2019). At the same time, symbiotic nitrogen fixation can be the main source of nitrogen in most farming systems (Petrychenko et al., 2020b). Nitrogen is of particular importance for pulses, as they fix it to a large extent from the air with the help of nodule bacteria (Pryshliak et al., 2023). However, in the context of global climate change, the reaction of soybean plants to the use of pre-sowing seed treatment and growth regulators may change (Mazur et al., 2020b). This issue requires further study.

## MATERIALS AND METHODS

Field research was conducted during 2018-2022 at the Research Farm «Ahronomichne» Vinnytsia National Agrarian University on gray medium loamy podzolized soils. The research program provides for agro-ecological substantiation and improvement of soybean cultivation technology in terms of seed yield in the Forest Steppe of the right-bank Ukraine, based on the results of research on the impact of genetic potential of the variety, pre-sowing seed treatment with the bacterial preparation Rizogumin, treatment of crops with the retardant chlormequat chloride of various concentrations (no treatment, 0.5%, 0.75% and 1% solution). The field experiments were laid out in quadruplicate, randomized, with a registered area of soybean plots of 25 $m^2$. The scheme of the field experiment is presented in Table 1.

Scientific research was carried out by conducting field and laboratory experiments. The research was conducted in accordance with generally accepted methods. Accounting of soybean crop density was carried out in the phase of full germination and before harvesting. Accounting for the density in the full germination phase, knowing the seeding rate, allows you to determine field germination. Accounting for density before harvesting allows you to calculate the survival rate of plants during the growing season using the Equation:

$$P = \frac{H \cdot 100}{G}, \quad (1)$$

where: $P$ – plant survival, %; $H$ – number of plants before harvesting, pcs. /$m^2$; $G$ – number of plants at the time of full germination, pcs. /$m^2$; 100 – number to convert to percentage.

To account for the density, a sampling method was used, forming a sample from segments of all rows diagonally, covering the entire length of the experimental area. In this case, the length of the segment was calculated by dividing the length of the plot on the accounting area by the number of rows. Summing up the number of plants

**Table 1.** Scheme of the experiment

| Factor A – variety | Factor B – pre-sowing seed treatment | Factor C – retardant concentration |
|---|---|---|
| $A_1$ – Azimuth | $B_1$ – no pre-sowing treatment | $C_1$ – without processing crops (c)* |
| $A_2$ – Golubka | $B_2$ – pre-sowing seed treatment with the bacterial preparation Rizogumin for soybeans (*Bradyrhizobium japonicum* M-8 or 46) | $C_2$ – 0.5 % concentration of chlormequat chloride retardant |
| | | $C_3$ – 0.75 % concentration of chlormequat chloride retardant |
| | | $C_4$ – 1 % concentration of chlormequat chloride retardant |

**Notes:** (c) control. The control variant was taken as a variant without pre-sowing treatment and without treatment of plants with retardant. On the day of sowing, soybean seeds on the control variant were treated with water.

in all segments and multiplying this value by the number of rows, we determined the total number of plants in the accounting area, which characterizes the density of crops in a particular variant. Harvest determination was carried out by continuous threshing of the accounting plot with a Sampo-500 combine. If necessary, exceptions were identified in the accounting plots. Before harvesting the seeds from the accounting plots, we first harvested the seeds on the exceptions and protective strips to avoid mixing these products with the accounting ones. We harvested the accounting plots by direct combining. After each plot was harvested, the seeds were packed in a bag with a label indicating the plot number, variant name, and replication number. After threshing, the seed bags were transported to the laboratory. To determine the mass of 1000 seeds, two weights of 500 seeds each were weighed with an accuracy of 0.01 g. If the difference between the weights of the samples exceeded 3%, a third sample was taken and weighed. The analysis of the crop structure was carried out using the test sheaf method, analyzing sheaf samples of legumes, the total number of stems in the sheaf was determined; number of productive stems in the sheaf; number of unproductive stems in the sheaf; attachment height of the lower beans – by measuring the distance from the root collar to the point of attachment of the lower bean in 25 plants taken from the sheaf sample; the average number of beans per plant, analyzing 25 plants; average number of seeds, weight of 1000 seeds and average weight of seeds per pod on the same 25 plants.

The number and weight of nodules were determined by the method of monoliths, imposing a frame of 300×167 mm (0.05 $m^2$). Therefore, knowing the area of the monolith and the average density of plants, we determined the number and weight of nodules per plant. Photosynthetic potential was determined by the method of Nichiporovich (1996); the amount of chlorophyll was determined by the method of alcohol weighing on a conditioned electrophotocolorimeter (KFK-2).

Nitrogen-fixing activity was determined by the Hardy acetylene method on a gas chromatograph Agilent GC System 6850 (USA). The amount of ethylene formed from acetylene during 1 hour of incubation under the action of nitrogenase of incubated sample was expressed in molar units of ethylene formed per 1 plant per 1 hour:

- μmol $C_2H_4$ / (plant · hour) – actual nitrogenase activity of the symbiosis;
- μmol $C_2H_4$ / (gram nodule · hour) – specific nitrogenase activity of the symbiosis.

To determine the symbiotic productivity of leguminous crops, we used indicators of total and active symbiotic potentials. The active symbiotic potential was calculated by Equation:

$$ASP = \frac{M_1 + M_2}{2} \cdot T, \quad (2)$$

where: $T$ – period between two adjacent analysis periods, days; $\frac{M_1 + M_2}{2}$ – average weight of nodules with lemoglobin during period $T$, kg/ha.

After harvesting the predecessor – winter wheat, stubble was peeled by 6–8 cm with a disk peeler LDG-15. The main soil cultivation - plowing – was carried out to a depth of 20–22 cm using a shelf plow. In the spring, early spring harrowing, leveling and subsequent loosening of the soil to the depth of seed placement were carried out. Before sowing, the seeds were treated with risogumine. Soybean planting was carried out on all variants simultaneously in first decade of May (May 6, 2018; May 3, 2019; May 13, 2019; May 1, 2020; May 10, 2021 and May 9, 2022). The retardant was applied by spraying the crops. Soybean harvesting was carried out by direct combining with a SAMPO-500 combine harvester.

## RESULTS AND DISCUSSION

Improved technologies for growing crops, including soybeans, which provide for the maximum use of biological factors, the formation of a stable structure of trophic relationships in microbial cenoses, that increase their resilience to life factors and their integration into the soil is a controversial issue for modern agricultural science and practice. The use of biological products based on strains of nitrogen-fixing, phosphorus-mobilizing microorganisms and producers of substances with phytohormonal and antifungal effects to improve plant mineral nutrition, stimulate their growth and protect them from harmful objects remains relevant today. In agrobiocenoses, not only species diversity but also their spatial distribution per unit area, which is significantly influenced by the weather conditions of the year, is important in plant relationships. Taking into account these factors of the cultivation technology, it is impossible to adjust the final density of the crop, which is necessary for the formation of the planned yield. A crop failure can occur as a result of crop thinning or, conversely, as a result of crop thickening, i.e. increased competition between plants. The results of studying the effect of retardants on different legumes indicate that with a unified mechanism of action, which is provided by the inhibition of gibberellins, there is a difference in species and even varietal responses of plants. The difference in reaction is determined by a complex of anatomical and physiological features of plants. First of all, it is a difference in the number of vascular fiber bundles, the ratio of xylem and phloem elements in them, the dynamics of growth and development in certain phases of the growing season. To date, research results indicate that by adjusting the dose of the product, its concentration, time and number of treatments in most crops, the habitus changes without reducing (or even increasing) yields. In some cases, the use of retardants improves the quality of the crop. The use of retardants also helps to increase the protein content of soybeans. The mechanism of action of chlormequat chloride is that water-soluble active ingredients are absorbed by the plant mainly through its green parts, and chlormequat chloride is absorbed by the root system. Thus, the basis of morphophysiological changes in plants under the action of retardants is the restructuring of the hormonal complex. The zone of influence of drugs of this group is the subapical meristem, where differentiation processes begin, which leads to changes in the anatomical structure of vegetative organs and their functional activity. It is changes in the processes of differentiation of subapical meristem under the action of retardants that led to better development of mechanical tissues, which contributed to an increase in stem strength, increased the resistance of plants to lodging, created technological advantages during harvesting. Observations of the dynamics of plant density of soybean varieties depending on the pre-sowing treatment of its seeds with the bacterial preparation Rizogumin and the retardant chlormequat chloride in different concentrations showed that with simultaneous sowing, seedlings also appeared almost simultaneously. Thus, in comparison with the control plots in the variants where pre-sowing seed treatment and two-time treatment of plants during the growing season with retardant were applied, number of preserved plants was 8.6–15.7 thousand pcs. /ha more compared to the control (Table 2).

Therefore, the maximum density of plants (585.9 ths. pcs./ha) was preserved before harvesting in the variant with the use of a bacterial preparation and two-time treatment of plants with a retardant during the growing season in the soybean variety Golubka. The minimum indicators were on the control variants of the Azimuth variety (539.5 ths. pcs./ha).

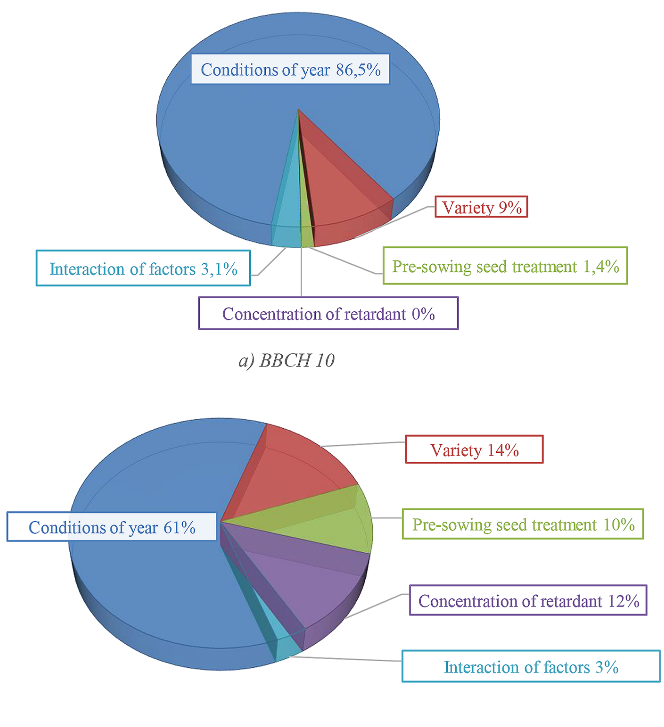
To visualize the influence of factors on the formation of plant density and its preservation at the time of harvesting, the results of the analysis of variance are presented in the form of a diagram (Figure 1a, Figure 1b).

According to the results of the conducted research, the variation of plant density in the phase of full germination from 629.0 to 643.7 ths. pcs./ha was calculated. But the difference between the options in this phase was not significant ($HIP_{05}$ = 3.56 ths. pcs./ha). There is a clear dominance of the influence of weather conditions (86.5%) during the sprouting phase of accounting. It should be noted that more favorable conditions for the germination period were in 2019 (precipitation in April and May – 25.9 and 42.7 mm) on average, the density of varieties was formed by variety Golubka 636.1 ths. pcs./ha. This variety has a slightly lower density (632.5 ths. pcs./ha) was formed in 2020 (precipitation of 22.8 and 18.6 mm, respectively). Precipitation deficit in April 2021 (only 7.3 mm) caused minimum plant density indicators (627.0 ths. pcs./ha). By the time of the pre-harvest surveys, the situation had changed somewhat. Thus, the impact of the year's conditions was the largest, but decreased to 61.0%. At the same time, the influence of the factors «variety», «pre-sowing seed treatment» and «concentration of retardant» increased. According to the results of observations, it was found that with simultaneous sowing, seedlings appeared almost simultaneously. Based on the analysis of the data obtained on soybean seed germination, it was found that the effect of bacterial preparation and retardant on the studied indicator is insignificant, since the intensity of seed germination is due to the endosperm, which contains its own reserve nutrients.It is obvious that the studied technological methods influenced the value of field germination and survival of the studied legumes BBCH 95 (Table 3).

The most favorable conditions for the growth, development and preservation of maximum number of soybean plants per unit area during the growing season were formed in a variant where

**Table 2.** Soybean planting density depending on technological methods of cultivation in conditions of Research Farm "Ahronomichne", ths. pcs./ha (average for 2018–2022)

| Variety | Pre-sowing seed treatment | Concentration of retardant, % | Time of accounting | |
|---|---|---|---|---|
| | | | germination phase BBCH 10 | before harvesting BBCH 95 |
| Azimuth | Untreated | untreated (c) | 629.0 | 539.5 |
| | | 0.5 | 629.0 | 549.4 |
| | | 0.75 | 629.0 | 556.9 |
| | | 1 | 629.0 | 550.4 |
| | Rizogumin | untreated | 631.1 | 550.6 |
| | | 0.5 | 631.1 | 555.4 |
| | | 0.75 | 631.1 | 569.8 |
| | | 1 | 631.1 | 557.8 |
| Golubka | Untreated | untreated (c) | 639.3 | 555.7 |
| | | 0.5 | 639.3 | 559.5 |
| | | 0.75 | 639.3 | 566.4 |
| | | 1 | 639.3 | 560.3 |
| | Rizogumin | untreated | 643.7 | 560.1 |
| | | 0.5 | 643.7 | 565.5 |
| | | 0.75 | 643.7 | 585.9 |
| | | 1 | 643.7 | 567.1 |
| $HIP_{05}$ | Factor A | | 1.27 | 2.01 |
| | Factor B | | 1.16 | 2.33 |
| | Factor C | | 1.11 | 2.22 |
| | Factors ABC | | 2.56 | 4.54 |




*b) BBCH 95*

**Figure 1.** The share of influence of factors on the formation of soybean plant density depending on the use of pre-sowing seed treatment with a bacterial preparation and the concentration of retardant: (a) germination phase BBCH 10, (b) before harvesting BBCH 95

**Table 3.** Field germination and survival of soybean depending on technological methods of cultivation in conditions of Research Farm «Ahronomichne», ths. pcs. /ha (average for 2018–2022)

| Variety | Pre-sowing seed treatment | Concentration of retardant, % | Field germination, % | Survivability, % |
|---|---|---|---|---|
| Azimuth | Untreated | untreated (c) | 87.43 | 85.77 |
| | | 0.5 | | 87.34 |
| | | 0.75 | | 88.54 |
| | | 1 | | 87.50 |
| | Rizogumin | untreated | 90.66 | 87.24 |
| | | 0.5 | | 88.01 |
| | | 0.75 | | 90.27 |
| | | 1 | | 88.38 |
| Golubka | Untreated | untreated (c) | 89.94 | 86.92 |
| | | 0.5 | | 87.52 |
| | | 0.75 | | 88.60 |
| | | 1 | | 87.64 |
| | Rizogumin | untreated | 92.36 | 87.01 |
| | | 0.5 | | 87.90 |
| | | 0.75 | | 91.02 |
| | | 1 | | 88.10 |

a bacterial preparation was used for pre-sowing seed treatment and with two treatments of crops with 0.75% retardant solution. It is obvious that optimal placement of plants reduces their competition and ensures uniform access of the crop to nutrients in soil. Usually, in liquefied crops, a significant mass of seeds is formed in the lower tier of plants, and under their weight, the branches bend to the ground, causing losses during harvesting. Thickened crops have a smaller number of lateral shoots, but the stem is quite thin, which contributes to significant lodging of plants. The final sowing density before harvesting significantly depends on the survival rate, which characterizes plant resistance to unfavorable growing conditions and depends primarily on characteristics of the variety and technological components of cultivation technology. Accounting for sowing density during growing season showed a decrease in number of plants in the process of their growth and development. Thus, in the variant where a bacterial preparation was used for pre-sowing seed treatment with two-time treatment of crops with a 0.75% solution of retardant, the survival rate was the highest and amounted to 90.27 and 91.02% in Azimuth and Golubka varieties, respectively, which is 5% more than in control.

It is necessary to note the greater stability of field germination of soybean seeds of Golubka variety depending on weather conditions at beginning of seed germination, which is very important for area of research, as there is often a lack of moisture both at the beginning of seed germination and during plant growth and development. In particular, on average, according to the research variants, the field germination of seeds of Golubka variety, depending on weather conditions at the beginning of seed germination, varied within 89.94–92.36%. That is, the smallest discrepancy between the field germination rates of seeds depending on weather conditions of the beginning of vegetation was in the variety Golubka – 14.9%, which indicates its greater plasticity to the variability of abiotic factors. Significantly significant interaction of studied technological methods of cultivation both on average by years of research and directly by years was not found. Favorable conditions for friendly germination were formed in 2021, where field germination was 89.03–92.23%, when in 2018, in the absence of precipitation during the sowing-germination period, germination was 70.66–74.34%, depending on the variant of pre-sowing seed treatment. When growing soybean plants, plant survival over the entire growing season is important, as this indicator determines the subsequent formation of productivity and yield. As a result of our research, it was found that the survival of soybean plants of Azimuth and Golubka varieties depended on pre-sowing seed treatment, weather and climatic conditions of cultivation that were formed during the years of research. It is known that before flowering phase-formation of beans (R1–R3) soybeans consume mainly nitrate nitrogen from the soil, and only after the R3 stage does the share of nitrogen consumption fixed from the air by bacteria increase and exceed the share of nitrate nitrogen. Therefore, providing the plant with available nitrogen in early stages is necessary to maximize genetic potential of plants. Numerous studies have shown that increasing the nitrogen content in soil with optimal phosphorus-potassium nutrition does not interfere with symbiosis of plants and nodule bacteria. With optimal nitrogen content but phosphorus deficiency (imbalance N:P) bacteria penetrate root system, but nodule bacteria do not form. Potassium deficiency reduces phloem movement of sugars to the root system, which also slows down formation of nodules and nitrogen fixation from air. The study of the process formation of symbiotic apparatus of soybean showed that on gray podzolic soils of the right-bank Forest-Steppe of Ukraine number and weight of nodules increases from the phase of the second or third trifoliate leaf, reaching a maximum in phase of full flowering, and gradually decreases during the period of full filling and maturation. Table 4 summarizes symbiotic efficiency of soybeans. Field and laboratory studies were conducted on such indicators of symbiotic efficiency as: nodule weight (per plant and per 1 ha), active symbiotic potential, mass of biologically fixed nitrogen and calculated the equivalent of ammonium nitrate (Figure 2, Figure 3) in accordance with generally accepted methods. According to the manifestation of studied traits, the variant with the treatment of seeds with Rizogumin and double treatment of crops with the retardant chlormequat chloride was distinguished: first – in phase of the 3rd trifoliate leaf, second – in the budding phase. Inoculation of seeds with the bacterial preparation Rizogumin provides an increase in weight of nodules in the Golubka variety by 0.33 g per plant, in terms of 1 ha it is 453 kg, active symbiotic potential amounted to 19.76 ths. kg day/ha, and mass of biologically fixed nitrogen in the air increases almost twice compared to the control, which corresponds to equivalent of ammonium nitrate 117.54 kg/ha. Treatment of plants during growing season with a retardant is inferior to option of inoculating soybean seeds according to the above indicators. Variant with Rizogumin seed treatment and double treatment of crops with chlormequat chloride retardant: first – in phase of the 3rd trifoliate leaf, second - in the budding phase improves results compared to seed inoculation alone. This is due to fact that in flowering phase, the plants have used 70% of nutrients and gradual death of bulbs begins, deficiency of

**Table 4.** Symbiotic efficiency of soybeans depending on technological methods of cultivation in conditions of Research Farm "Ahronomichne" (average for 2018–2022)

| Variety | Pre-sowing seed treatment | Concentration of retardant, % | Bulb weight | | Active symbiotic potential, ths. kg. days/ha | Weight of biologically fixed nitrogen, kg/ha |
|---|---|---|---|---|---|---|
| | | | per 1 plant, g | per 1 ha, kg | | |
| Azimuth | Untreated | untreated (c) | 0.22 | 178 | 7.75 | 40.41 |
| | | 0.5 | 0.27 | 182 | 7.76 | 41.08 |
| | | 0.75 | 0.33 | 185 | 7.82 | 42.15 |
| | | 1 | 0.30 | 183 | 7.79 | 41.33 |
| | Rizogumin | untreated | 0.50 | 343 | 13.97 | 74.32 |
| | | 0.5 | 0.58 | 349 | 14.22 | 75.65 |
| | | 0.75 | 0.63 | 357 | 16.12 | 78.12 |
| | | 1 | 0.60 | 352 | 15.17 | 76.31 |
| Golubka | Untreated | untreated (c) | 0.36 | 221 | 15.72 | 77.38 |
| | | 0.5 | 0.42 | 226 | 15.88 | 77.87 |
| | | 0.75 | 0.49 | 232 | 16.46 | 79.06 |
| | | 1 | 0.44 | 229 | 15.97 | 78.23 |
| | Rizogumin | untreated | 0.69 | 453 | 19.76 | 117.54 |
| | | 0.5 | 0.76 | 470 | 20.32 | 119.87 |
| | | 0.75 | 0.91 | 489 | 22.34 | 124.56 |
| | | 1 | 0.80 | 476 | 20.68 | 120.70 |

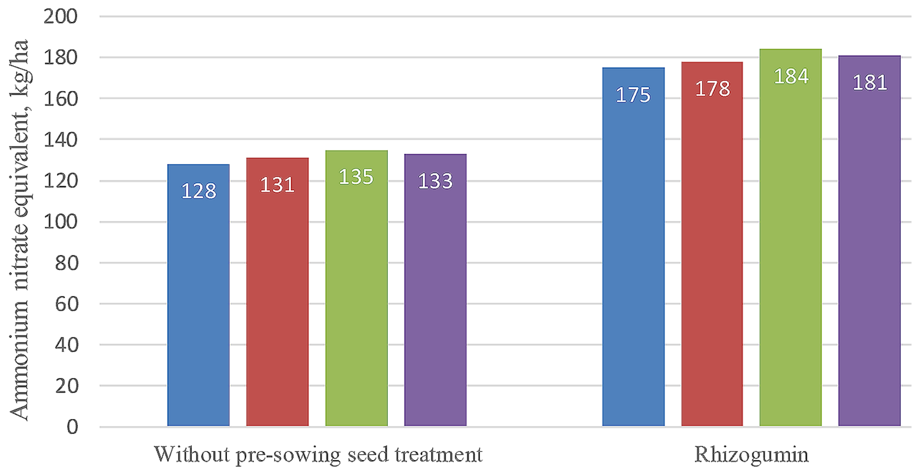



**Figure 2.** The equivalent of ammonium nitrate on Azimuth soybean variety depending on technological methods of cultivation in conditions of Research Farm "Ahronomichne", kg/ha (average for 2018–2022)

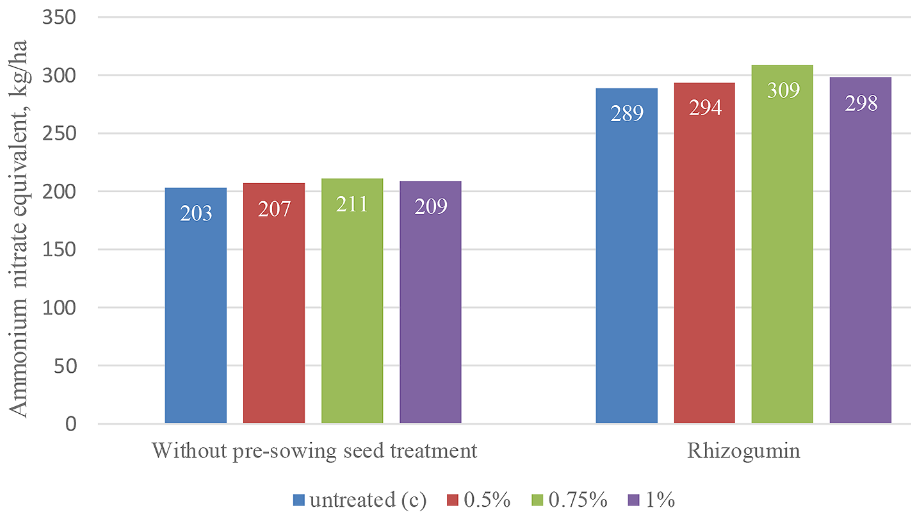



**Figure 3.** The equivalent of ammonium nitrate on Golubka soybean variety depending on technological methods of cultivation in conditions of Research Farm "Ahronomichne", kg/ha (average for 2018–2022)

nitrogen for formation of generative organs (productivity) is solved by foliar fertilization. So, the maximum symbiotic potential of soybean variety Golubka was formed in variant with two-time treatment of crops with the retardant chlormequat chloride: first – in phase of the 3rd trifoliate leaf, second – in the budding phase and sowing with inoculated seeds with Rizogumin. The weight of bulbs per plant reaches 0.91 g and is 489 kg/ha, weight of biologically fixed nitrogen remaining in soil – 124.56 kg/ha, which is equivalent to ammonium nitrate – 309 kg/ha. A similar trend with slightly lower rates was recorded on Azimuth soybean varieties, which is a genetically determined trait. Thus, the symbiotic potential of soybean variety Azimuth was formed on the variant with two-time treatment of crops with retardant chlormequat chloride: first – in phase of the 3rd trifoliate leaf, second - in the budding phase and sowing with inoculated seeds with Rizogumin also had maximum values within this variety. The weight of bulbs per plant reaches 0.63 g and 357 kg/ha, weight of biologically fixed nitrogen remaining in the soil – 79.06 kg/ha, which is equivalent to ammonium nitrate – 184 kg/ha. Thus, the bacterial preparation and 0.75% concentration of retardant increases the active symbiotic potential of the variety Golubka by 29.63% compared to control. Therefore, according to results of analysis of variance, the share of influence of factors studied on the symbiotic efficiency of soybean was determined (Figure 4).

Thus, seed bacterization provided an increase in active symbiotic potential by 30.6%, 22.4% – variety, treatment of soybean crops with chlormequat chloride in different concentrations ensured the formation of 9.2% of yield and 15.4% – interaction of factors, 13.4% – hydrothermal conditions and other unaccounted for factors. It has been experimentally proven that in order to maximize the individual productivity and yield of soybean seeds, it is necessary to apply two-time treatment of crops with the retardant chlormequat chloride: first – in phase of the 3rd trifoliate leaf, second – in the budding phase. It is known that during these periods, soybean plants lay and develop generative organs. In turn, retardants affect synthesis or activity of gibberellins, which are responsible for flower formation and fertility. As a result, the increased outflow of nutrients to generative organs was accompanied by an increase in seed yield. The analysis of elements of yield structure soybean varieties Azimuth and Golubka showed that during research fieldwork their value was significantly influenced by the factors that were put under study. The results of studies of individual productivity of soybean seeds showed (Table 5), that maximum quantitative indicators of individual productivity of the variety Golubka, namely the number of beans per plant (17.9 pcs.) and number of seeds (32.1 pcs.) per plant were obtained in case of pre-sowing seed treatment with the bacterial preparation Rizogumin and treatment of crops with a 0.75% solution of the retardant chlormequat chloride. The formation of quantitative indicators on plant during the treatment with retardant was inferior to pre-sowing treatment with a bacterial preparation, but differences were within error of experiment. The combined treatment of seeds with a bacterial preparation and treatment of crops with a 0.75% solution of retardant stimulated the growth of number of beans per plant and indicator was higher than the control variant, and growth of number of grains was within error of experiment. The minimum quantitative indicators of individual productivity of soybean variety Azimuth, namely the number of beans per plant (12.1 pcs.) and number of seeds (23.4 pcs.) per plant were obtained in control.

The weight of 1000 seeds on average in experiment was 160.1 g in Azimuth and 166.7 g in Golubka, which is a genetically determined trait. Therefore, increase in weight of 1000 seeds in experimental variants was similar to other indicators of individual productivity. Pre-sowing treatment of soybean seeds contributed to obtaining a largest weight of 1000 seeds – 170.1 g, which is 5.9 g more than in the control variety Golubka. When treating crops with retardant, a significant excess of indicator over the control variant was also recorded. The formation of total seed productivity depended on total interaction of number seeds per plant (Figure 5a) and weight of 1000 seeds (Figure 5b). The results of structural formation of seeds on plant indicate the dependence of trend influence of pre-sowing seed treatment with preparation on quantitative indicators soybean plant productivity. It was found that maximum realization of genetic potential, and as a consequence, indicators of individual productivity of

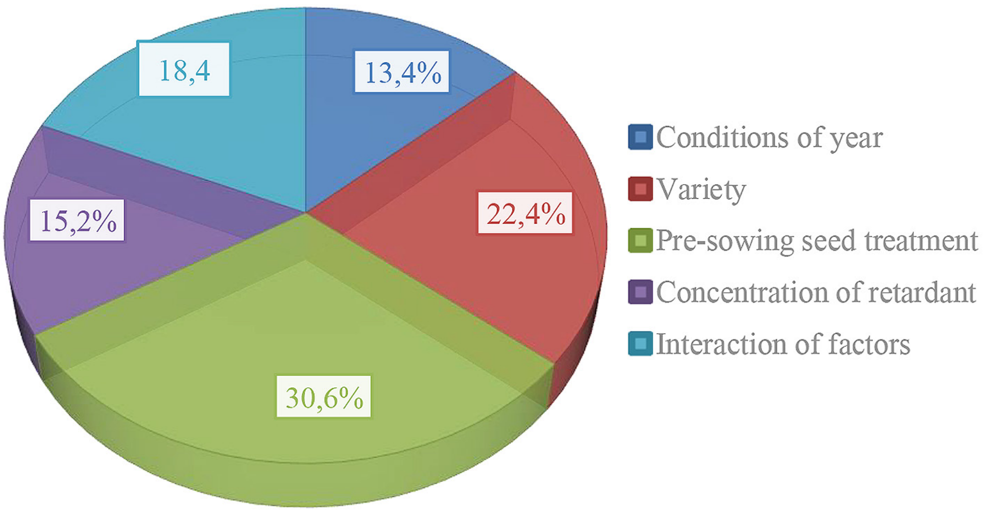



**Figure 4.** The share of influence of factors applying pre-sowing seed treatment with a bacterial preparation and crop treatment with a retardant on the symbiotic efficiency of soybean

**Table 5.** Individual productivity of soybean varieties depending on technological methods of cultivation in conditions of Research Farm "Ahronomichne", t/ha (average for 2018–2022)

| Variety | Pre-sowing seed treatment | Concentration of retardant, % | Number on a plant, pcs. | | Grain weight, g | |
|---|---|---|---|---|---|---|
| | | | beans | seeds | 1000 seeds | from a plant |
| Azimuth | Untreated | untreated (c) | 12.1 | 23.4 | 156.4 | 2.73 |
| | | 0.5 | 12.3 | 23.8 | 157.7 | 2.78 |
| | | 0.75 | 12.6 | 24.4 | 159.0 | 2.86 |
| | | 1 | 12.4 | 24.0 | 158.7 | 2.80 |
| | Rizogumin | untreated | 13.4 | 25.4 | 159.8 | 3.11 |
| | | 0.5 | 13.8 | 25.9 | 160.0 | 3.16 |
| | | 0.75 | 14.4 | 27.1 | 166.1 | 3.35 |
| | | 1 | 14.0 | 26.5 | 163.2 | 3.24 |
| Golubka | Untreated | untreated (c) | 14.6 | 26.9 | 164.0 | 3.29 |
| | | 0.5 | 14.9 | 27.4 | 164.7 | 3.34 |
| | | 0.75 | 15.6 | 28.7 | 166.8 | 3.45 |
| | | 1 | 15.1 | 27.9 | 165.4 | 3.41 |
| | Rizogumin | untreated | 16.4 | 28.6 | 166.2 | 3.54 |
| | | 0.5 | 16.8 | 29.9 | 167.9 | 3.67 |
| | | 0.75 | 17.9 | 32.1 | 170.1 | 3.88 |
| | | 1 | 17.1 | 30.6 | 168.7 | 3.70 |

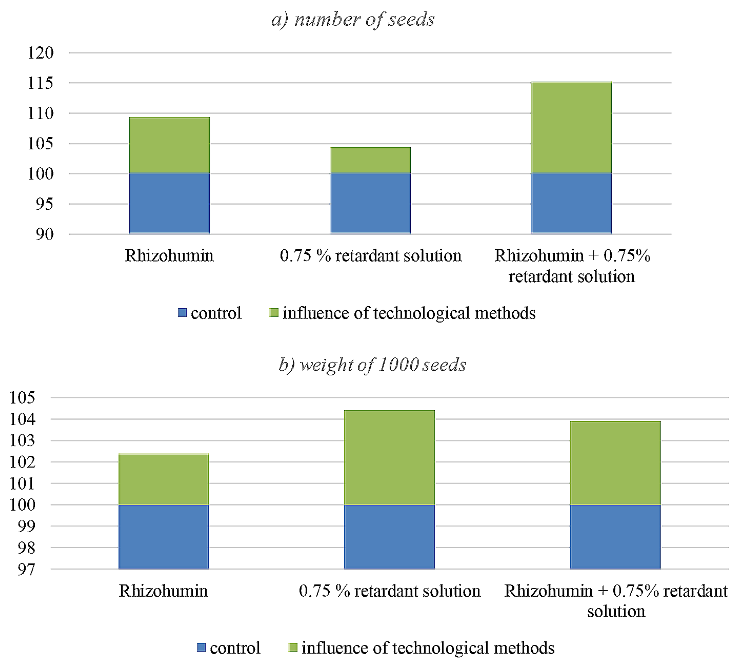



**Figure 5.** Formation: (a) number of seeds and, (b) weight of 1000 seeds of soybean plants depending on pre-sowing seed treatment and concentration of retardant (average for 2018–2022)

soybeans is created under condition of pre-sowing seed treatment with the bacterial preparation Rizogumin and treatment of crops with the retardant chlormequat chloride: first – in phase of the 3rd trifoliate leaf, second – in the budding phase. In this variant of experiment, the largest weight of seeds per plant was noted in the variety Golubka – 3.88 g, an increase of 0.61 g (or 15.2 than in variant where seeds not treated. Noted that among variants of experiment, the use of Rizogumin and 0.75% retardant solution contributed to highest yield structure indicators. The increase studied parameters in this variant compared to the control was 15.2%. The research has established that combination of pre-sowing seed treatment with a bacterial preparation and plant treatment during growing season with a retardant has a positive effect on increasing yield of the varieties subject to study. The use of retardants, as well as level of their impact on plant productivity, remains an important issue, as in many cases the change in habitus is complex, covering entire plant, including reproductive organs. Grain yields are determined by genetic characteristics of species and vary in different ranges depending on variety (Table 6). Thus, the treatment of vegetative soybean crops with the retardant chlormequat chloride at a concentration of 0.75% in the 3rd trifoliate leaf stage and budding provides the best conditions for growth, development and formation of high yields of soybean varieties at the level of 2.39–2.58 t/ha. According to analysis of variance, proportion of influence of factors studied on formation of soybean seed yield was determined (Figure 6). Thus, pre-sowing seed treatment ensured formation of 17.4% of seed yield, 29.2% – variety, treatment of soybean crops with chlormequat chloride in different concentrations ensured formation of 20.2% of yield and 6.1% – interaction of factors, 27.1% – hydrothermal conditions and other unaccounted for factors. The yield index has a parabolic dependence on the inoculant within a certain concentration of retardant. If in control variant the yield index was low due to a lack of nutrients and differentiation of a small number of generative organs, then when using a two-time treatment of crops with the retardant chlormequat chloride: first – in phase of the 3rd trifoliate leaf, second - in the budding phase, it was reduced by accumulating a significant amount of by-products (Figure 7).

## CONCLUSIONS

The maximum density of soybean plants (585.9 ths. pcs./ha) before harvesting was provided by the variety Golubka with use of the bacterial preparation Rizogumin and two-time treatment of plants with a plant growth regulator with a retardant effect at 0.75% concentration. It was proved that the field germination of seeds during the research period depended on weather conditions, and survival for harvesting period was

**Table 6.** Seed yield of soybean varieties depending on technological methods of cultivation under conditions of Research Farm "Ahronomichne", t/ha (average for 2018–2022)

| Variety | Pre-sowing seed treatment | Concentration of retardant, % | Years | | | | | Average for 2018–2022 | Increase to control, t/ha |
|---|---|---|---|---|---|---|---|---|---|
| | | | 2018 | 2019 | 2020 | 2021 | 2022 | | |
| Azimuth | Untreated | untreated (c) | 1.90 | 1.92 | 2.21 | 2.11 | 2.16 | 2.06 | - |
| | | 0.5 | 1.91 | 1.93 | 2.33 | 2.16 | 2.27 | 2.12 | 0.06 |
| | | 0.75 | 1.99 | 2.03 | 2.49 | 2.34 | 2.35 | 2.24 | 0.18 |
| | | 1 | 1.95 | 1.99 | 2.41 | 2.18 | 2.32 | 2.17 | 0.11 |
| | Rizogumin | untreated | 1.96 | 2.00 | 2.42 | 2.19 | 2.31 | 2.18 | 0.12 |
| | | 0.5 | 2.00 | 2.04 | 2.50 | 2.35 | 2.36 | 2.25 | 0.19 |
| | | 0.75 | 2.12 | 2.15 | 2.84 | 2.41 | 2.43 | 2.39 | 0.33 |
| | | 1 | 2.05 | 2.10 | 2.61 | 2.38 | 2.36 | 2.30 | 0.24 |
| Golubka | Untreated | untreated (c) | 1.99 | 2.04 | 2.45 | 2.35 | 2.22 | 2.21 | - |
| | | 0.5 | 2.01 | 2.06 | 2.71 | 2.38 | 2.29 | 2.29 | 0.08 |
| | | 0.75 | 2.10 | 2.16 | 2.90 | 2.44 | 2.40 | 2.39 | 0.18 |
| | | 1 | 2.03 | 2.09 | 2.75 | 2.40 | 2.33 | 2.32 | 0.11 |
| | Rizogumin | untreated | 2.15 | 2.19 | 3.01 | 2.47 | 2.48 | 2.46 | 0.25 |
| | | 0.5 | 2.21 | 2.24 | 3.08 | 2.56 | 2.66 | 2.55 | 0.34 |
| | | 0.75 | 2.29 | 2.37 | 3.17 | 2.83 | 2.69 | 2.67 | 0.46 |
| | | 1 | 2.25 | 2.32 | 3.00 | 2.74 | 2.59 | 2.58 | 0.37 |
| $HIP_{0.05}$ t/ha (soybean): A-0.02; B-0.03; C-0.03; AB-0.02; AC-0.04; BC-0.14; ABC-0.05<br>2018. $HIP_{0.05}$ t/ha: A-0.01; B-0.03; C-0.03; AB-0.02; AC-0.02; BC-0.02; ABC-0.04<br>2019. $HIP_{0.05}$ t/ha: A-0.02; B-0.01; C-0.02; AB-0.03; AC-0.03; BC-0.03; ABC-0.04<br>2020. $HIP_{0.05}$ t/ha: A-0.02; B-0.03; C-0.03; AB-0.02; AC-0.02; BC-0.02; ABC-0.05<br>2021. $HIP_{0.05}$ t/ha: A-0.02; B-0.01; C-0.02; AB-0.03; AC-0.03; BC-0.03; ABC-0.06<br>2022. $HIP_{0.05}$ t/ha: A-0.03; B-0.02; C-0.03; AB-0.03; AC-0.02; BC-0.02; ABC-0.03 | | | | | | | | | |

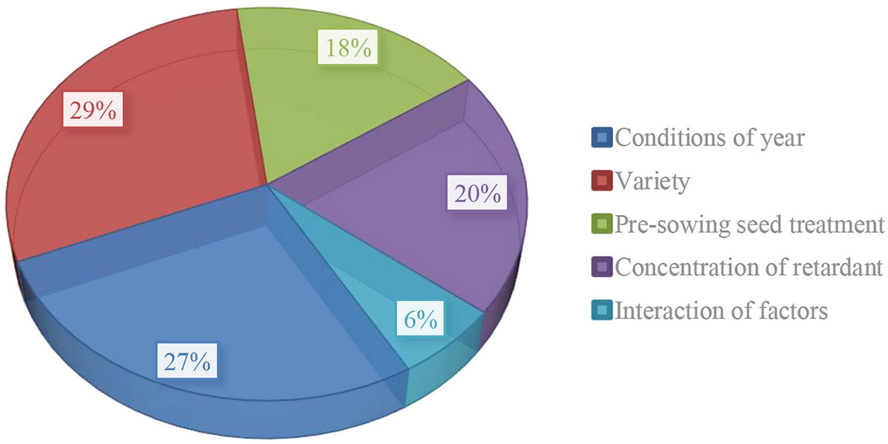



**Figure 6.** The share of influence of factors on formation yield under pre-sowing seed treatment with a bacterial preparation and concentration of retardant: 1 – control; 2 – no pre-sowing seed treatment + 0.5 % retardant solution; 3 – no pre-sowing seed treatment + 0.75 % retardant solution; 4 – no pre-sowing seed treatment + 1.0 % retardant solution; 5 – pre-sowing seed treatment + no retardant; 6 – pre-sowing seed treatment + 0.5 % retardant solution; 7 – pre-sowing seed treatment + 0.75 % retardant solution; 8 – pre-sowing seed treatment + 1.0 % retardant solution.

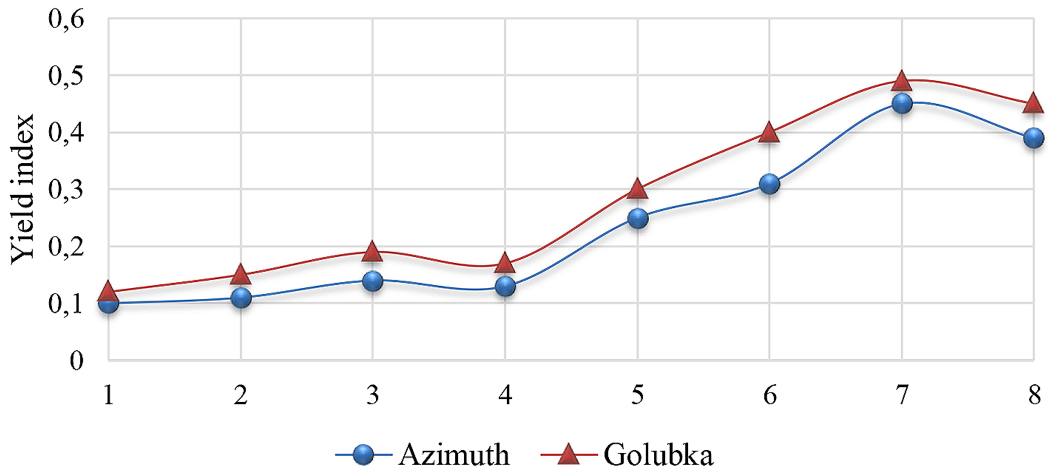



**Figure 7.** Soybean yield index depending on pre-sowing seed treatment with a bacterial preparation and retardant concentration, average for 2018–2022.

maximum in variant of pre-sowing seed treatment with bacterial preparations and use of a plant growth regulator with retardant action. The most effective active symbiotic potential, compared to variant without treatment, was variant with pre-sowing seed treatment and treatment of crops with a 0.75% solution of retardant concentration. Therefore, the active symbiotic potential of soybean variety Golubka was higher than that of Azimuth and, depending on variant of experiment, varied within 15.72–22.34 ths. kg, days/ha. The results of studies of individual productivity of soybean seeds showed that maximum quantitative indicators of the variety Golubka: number of beans per plant (17.9 pcs.) and number of seeds (32.1 pcs.) from one plant were obtained in case of pre-sowing seed treatment with the bacterial preparation Rizogumin and treatment of crops with a 0.75% solution of the retardant chlormequat chloride. In this variant of the experiment, the largest weight of seeds per plant was noted in the variety Golubka – 3.88 g, which is 0.61 g (or 15.2%) more than in the variant where the seeds were not treated. Thus, maximum soybean yield is from 2.43 t/ha in the Azimuth variety, up to 2.67 t/ha in Golubka variety was established on plots with pre-sowing seed treatment with the bacterial preparation Rizogumin and treatment of crops with a 0.75% solution of the retardant chloromequat chloride. The increase amounted to 15.23–16.28%.

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