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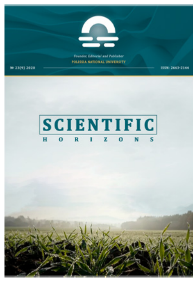

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The Effect of Cultivation Conditions on the Nitrogen Fixation and Seed Yield of three Ukrainian varieties of Soybean

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Abstract. The relevance of the research topic is determined by the search for new technological methods of growing soybeans. Therefore, the specifics of the formation of productivity of different varieties of soybeans were investigated depending on a number of factors, such as: dates, methods of sowing and the rate of sowing. The purpose of the research was theoretical substantiation and practical advises of sowing dates and methods, sowing rates of different varieties of soybeans. Indicators of the influence of light intensity, fertilizer application, changes in seed sowing rates and different variants of soybean sowing distance on biological nitrogen fixation of soybeans were analyzed. As a result, regularities were established and a scientific substantiation of provisions was carried out, recommendations for production and scientifically based methods of soybean cultivation technology were developed, which ensure an increase in crop productivity by 15-25%. The developed practical recommendations for increasing soybean production are used in the farms of the region and beyond to solve an important problem – increasing the production of fodder and food protein and vegetable oil. Changing the sowing rate from 0.5 to 0.8 M seeds/ha for row sowing contributed to an increase in the attachment height of the lower beans, which, in turn, contributes to a reduction in crop losses during crop harvesting. Sowing rate had a greater influence on soybean yield than the sowing method. The best conditions were obtained when sowing 0.7 M seeds/ha of similar seeds. During the research, the Romantyka variety showed the highest yield of 3.07 t/ha under the row method of sowing, the sowing rate of 0.8 M seeds/ha and the second sowing period

Keywords: plant growing, light intensity, sowing terms, norms and methods, root nodule, inter-row distance, seeding rate

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INTRODUCTION

Soybean is the world's most important seed legume, cultivated on an estimated 121 million ha worldwide, with a total production of 334.9 million tons in 2018 (FAOSTAT, 2017). It is one of the largest sources of animal feed in the world (Patil *et al.*, 2017) and is also used as a source of high-quality protein in the human diet (Rizzo & Baroni, 2018). With a protein content of 36-42% protein and an oil content of 15-25%, soybean is a rich source of protein and is the largest oilseed crop in the world (Vinnichek *et al.*, 2018; De Luca & Hungria, 2014). A large amount of nitrogen is required by the grain legumes to synthesize seed storage proteins, a substantial portion of which is obtained by the process of symbiotic biological nitrogen fixation. Out of 193 million tons of nitrogen fixed annually by biological means, crop legumes fix about 21.5 million tons, and the contribution from soybean is about 77% of this amount (Weil & Brady, 2017; Herridge *et al.*, 2008). Therefore, efforts aimed towards increasing the efficiency of symbiotic biological nitrogen fixation and seed yield in legumes, particularly in soybean, can contribute significantly towards sustainable food production.

The nitrogen fixation carried out by plant-bacteria symbiotic association is affected by the environmental factors. Optimization of these factors can potentially increase the seed yield of soybean and that of other legumes and help in reducing the use of chemical fertilizers. Each year >100 million tons of nitrogen is applied to the crops worldwide (Heffer & Prud'Homme, 2016; Umburanas *et al.*, 2018). The production and application of nitrogen fertilizers utilize about 1.1% of the world's energy (IFA, 2009) and represent about 1.5% of the global GHG emissions (CCAFS, 2019). Approximately one-third of the GHG emissions from agriculture is in the form of N_2O, a byproduct of the degradation of nitrogen fertilizers and with a global warming potential 265 times that of carbon dioxide (Blanco *et al.*, 2014). Therefore, gradual replacement of chemical fertilizers with symbiotically fixed nitrogen can play an important role in limiting the environmental damage due to chemical fertilizers. Improvements in the nitrogen fixation capabilities of legumes particularly that of soybean, can contribute significantly towards this transition. Increase in nitrogen fixation efficiency of grain legumes can also reduce the need for bringing additional land under cultivation to keep up with the growing world food demand (Getachew Gebrehana & Abeble Dagnaw, 2020).

D.F. Herridge *et al.* (2008) in their researches calculated nitrogen fixation by the crop legume–rhizobia symbioses. They determined the role of nitrogen fixation in underpinning legume productivity and how highly efficient rhizobia–soybean symbioses might be achieved in commercial practice.

X.-Y. Lin *et al.* (2022) in their researches studied interactions between hydrogen sulphide and rhizobia modulate the physiological and metabolism process during water deficiency in soybeans.

Temperature, soil moisture, soil mineral nitrogen, salinity, soil oxygen (Atieno *et al.*, 2019; Mathenge *et al.*, 2019), and soil acidity are major factors affecting the symbiotic nitrogen fixation in legumes (Pahari *et al.*, 2021).

A study of the influence of light intensity, fertilizer application, irrigation, seeding rate and row spacing on nitrogen fixation and yield for three soybean varieties was conducted.

The purpose of the research was to develop theoretical explanations and practical advice on increasing the productivity of soybeans by improving the elements of the cultivation technology, taking into account the biological characteristics of the varieties.

MATERIALS AND METHODS

Laboratory experiments were carried out at the Institute of Crops and Grassland Science, University of Hohenheim (Stuttgart, Germany) and at the Department of Plant Growing, Poltava State Agrarian University (Poltava, Ukraine). The seeds of Romantica variety were obtained from Yuriev Institute of Plant Breeding, National Academy of Science, (Kharkiv, Ukraine); Ustya variety from Institute of Agriculture, National Academy of Science, (Kyiv, Ukraine) and Vorskla variety from Soy Research Institute (Globyno, Ukraine).

Plant growth conditions. The soybean seeds of Romantica variety were sown in 800 ml pots containing vermiculite and sand in a ratio of 1:1. A single seed was sown in each pot, and 6 pots were maintained in a RK-340 CH growth chamber (Kambič d.o.o, Semič, Slovenia) at 27°C, 70% RH, 460 μmol mol^{-1} CO_2 and 16/8 light/dark photoperiod at 60 W/m^2 or 120 W/m^2. The distance between the plants was 20 cm. The plants were harvested at 5^{th} trifoliate (V5), flowering (R2), and full pod stages (R4). One set of plants at full bloom (R2) stage was used to study the effect of dark periods on the nitrogen fixation by the root nodules. These plants were subjected to a continuous dark period of 48 h before measuring the BNF rate.

Estimation of nitrogenase activity in the root nodules.

The rate of nitrogen fixation in the root nodules was determined by using the acetylene reduction method (Gremaud & Harper, 1989). The roots with attached nodules were placed in a hermetically sealed glass vial of 75 ml capacity, which was filled with 10% acetylene gas. The flask was incubated for 1 h, and the ethylene gas formed in the flask was quantified on a gas chromatograph equipped with a flame ionization detector (Agilent GC system 6850; Agilent Technologies, Santa Clara, CA, USA). The separation of gases was performed on a Supelco Porapak N column at a furnace temperature of 55°C and a detector temperature of 150°C. The carrier gas was helium (50 ml.min^{-1}) and the sample volume injected into the gas chromatograph was 1 ml.

The amount of ethylene formed in 1 hour by the action of nitrogenase was expressed as nmol.plant^{-1}.min^{-1}.

Measurement root nodule respiration. The root nodule respiration was studied by the method of Nelson and Wood with some modifications (17). A sample of the test material (2 g) was placed into a gauze bag and fixed with a hook to a rubber cork. Twenty-five milliliters of 0.25 N solution of Ba $(OH)_2$ were quickly poured into a flask, and 3 drops of phenolphthalein were added. The flask was immediately sealed with the cork, bringing the sample inside the flask (the gauze bag could pass easily through the neck of the flask and did not touch the solution present in the flask).

The control flask was set up in the same manner but without the test material. After 20 min the test material was removed from the experimental flask, and it was quickly closed with a stopper. The solutions in the experimental and the control flasks were titrated with 0.01 N HCl until the disappearance of the pink color. The flasks are periodically shaken so that a $BaCO_3$ film does not form on the surface of the liquid. The amount of CO_2 evolved per gram of plant tissue per hour was calculated from the volume of HCl consumed, given that 1 ml of 0.01 N HCl is equivalent to 0.22 mg of CO_2 produced by the plant material.

Field Experiments. Three varieties of soybean, Romantica, Ustya, and Vorskla, were used to study the effect of inter-row spacing and seeding rate on the number and mass of root nodules and the seed yield. The size of the study plots was 25 m^2, and the seeds of each variety were sown in rows with 15 cm or 45 cm spacing and at rates of 0.5, 0.6, 0.7 and 0.8 million seeds/ha. The experiments were conducted between April 26 and May 10 of the year 2017 and repeated three times in the same duration during the years 2018, 2019 and 2020. The average temperatures and rainfalls for the study period were: 2017 – 13.4°C, 7.35 mm; 2018 – 18.3°C, 5.05 mm; 2019 – 15.6°C, 6.08 mm; 2020 – 15.1°C, 12.9 mm. The soil of the experimental site was podzolic medium-textured loam chernozem with a humus content of 3.7%, and a pH 5.6. The nodule mass and number for each variety were determined three times – after the formation of symbiosis (1st selection – 35 days after emergence, 5th trifoliolate stage) and during the period of active nitrogen fixation (2nd and 3rd selection – 45 and 55 days after emergence). At maturity, seed harvesting was carried out using small grain harvesters Sampo (Sampo-Rosenlew, Pori, Finland). The yield of the seeds and the green mass were determined from the samples taken from an area of 1 m^2 from each field. The beans were plucked from the plant and opened to collect the seeds, which were counted and weighed. Statistical analysis was performed using Microsoft Excel and Statistica programs.

RESULTS AND DISCUSSION

The effect of light intensity on the nitrogen fixation. The effect of light intensity on the dry weight of the plants and the nodules, and the rate of nitrogen fixation in the nodules was studied at V1, R1, and R7 stages. The plant and nodule dry weight per plant was significantly increased at 120 W/m^2 light intensity, compared to 60 W/m^2 (Figs. 1; 2).

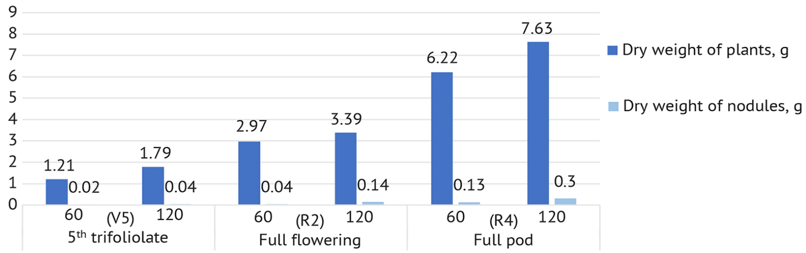

***Figure 1**. Effect of light intensity (60 or 120 W/m^2) on dry matter content of plants and nodules*
***Source:** authors' development*

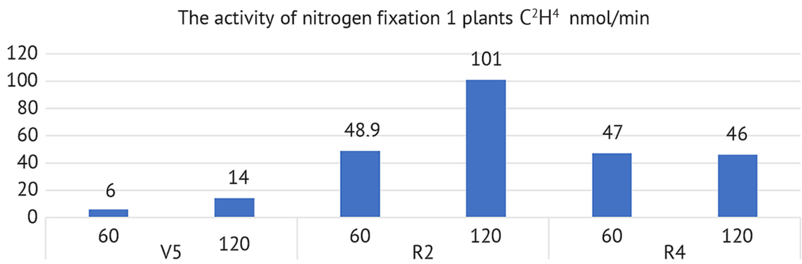

***Figure 2**. Rate of nitrogen fixation (measured as rate of acetylene reduction (nmol/plant/min) as affected by light intensity in soybean plants*

The nitrogen fixation rate (expressed as nmol/plant/min of C_2H_4 production) was higher in the plants grown under the light of 120 W/m^2 at the V1 and R1 stages. The nitrogen fixation rate was not affected by the light intensity at the R7 stage and was, in fact, slightly lower at 120 W/m^2 light intensity than at 60 W/m^2. The increased rate of nitrogen fixation during the V1 and R1 stages at higher light intensity was due to greater growth and higher masses of the nodules and not due to greater specific activity of the nitrogenase enzyme in the nodules. At R7 stage though the mass of the nodules per plant is higher than in earlier stages, the nitrogen fixation is reduced, suggesting a decrease in the specific activity of the nitrogenase enzyme at this stage. Earlier studies indicated that a light of 400-500 μmol/m^2/s (~ 87-109 W/m^2) was optimum for soybean growth and development. Therefore, light intensities of 60 and 120 W/m^2 were used in the study. Earlier studies have also reported a positive correlation between the light intensity and the nitrogen fixation rates in soybean up to a certain light intensity. The reduction in nodule mass and number per plant with decreasing light intensity has been reported (Lin *et al.*, 2022; Jańczak-Pieniążek *et al.*, 2021; Yang *et al.*, 2022). The drop-in nitrogen fixation rates in the green bean filing stage have been reported (Prusinski & Nowicki, 2020).

Soybean monitoring the effect of light intensity on the root development, and nitrogen fixation rates at three growth stages of soybean under the conditions of infection by native soil symbiotic bacteria were studied. The research revealed two important characteristic of nitrogen fixation in soybean: 1) at later stages of growth when the rate of nitrogen fixation drops, light of higher intensity cannot boost the nitrogen fixation rate, 2) this drop in nitrogen fixation at later stages of growth is due to decrease in specific activity of nitrogenase in the nodules, as nodule mass and number did not decrease at R7 stage.

Effect of soil nitrogen content on the initiation and development of root nodules.

There are conflicting views on the use of inorganic nitrogen fertilizer for increasing the yields of soybean. Reed *et al.* (2019) have advocated against the use of supplemental nitrogen for legumes, while other authors have recommended the use of small amounts of inorganic nitrogen to achieve good nodulation and yields (Rizzo & Baroni, 2018, Arachchige *et al.*, 2020). The amount of nitrogen required to maintain plant growth and development prior to the initiation of nitrogen fixation in soybean plants is small and can be provided by the soil reserves. During the period of active growth and development of soybeans, especially during the formation of the beans, nitrogen-deficient conditions in the soil lead to the development of a defective photosynthetic apparatus with a low photosynthetic efficiency that cannot be improved without providing supplemental nitrogen. An efficiently functioning photosynthetic apparatus is thus a prerequisite for the development of healthy root nodules. The number of nodules that developed on the roots of the plants varied with the soil nitrogen content and the stage of the plant growth (Table 1).

***Table 1**. The effect of mineral nitrogen fertilizer on the number and mass of root nodules per plant*

Indicators	**Phases of growth and development of soybean plants**								
	V1-V3 stage			**R1-R2 stage**			**R3-R6 stage**		
	Without fertilizers	N_{30}	N_{60}	Without fertilizers	N_{30}	N_{60}	Without fertilizers	N_{30}	N_{60}
Number of nodules per 1 plant, pcs.	3.0±1.2	3.5±1.6	4.0±1.2	7.2±2.0	6.3±1.5	6.1±1.7	12.8±4.3	10.3±1.6	8.1±1.9
The mass of nodules per 1 plant, mg	23±3.5	28±3.6	34±3.4	91±5.4	63±6.3	50±5.6	287±14.9	201±5.8	153±6.5
Nitrogen content in soil (mg/kg of soil) $N-NO_3$	10.8±2.2	17.5±3.9	20.2±2.9	9.4±2.2	19.7±2.6	21.1±2.3	4.1±1.7	6.7±2.5	7.2±2.3
$N-NH_4$	6.8±2.0	8.6±3.0	10.3±3.3	14.8±2.0	15.7±2.5	15.9±3.9	8.0±1.7	9.2±3.3	9.7±3.8
$N-NO_3$: $N-NH_4$	1.59	2.0	2.0	0.64	1.25	1.32	0.51	0.73	0.74

Source: *authors' development*

During the first three to four weeks of growth, soybeans actively use inorganic nitrogen from the soil. In the first-third trifoliate stage (V1-V3), a greater number of nodules per plant were noted in areas with fertilizer application: 3.5 in areas with 30 kg/ha, 4.0 in areas with 60 kg/ha and 3.0 without fertilizer application. The average mass of the nodules per plant was also higher in the areas with fertilizer: 28 g in plants growing in 30 kg/ha and 34 g in plants growing in areas with 60 kg/ha fertilizer application. The average mass of the nodules per plant in areas without fertilizer application was only 23 g.

In later stages of plant growth, fertilizer application had a negative effect on the nodule number and nodule mass. In the R1-R2 stages, there was an increase in the number of nodules in areas without fertilizers: 7.2±1.81 in unfertilized areas, 6.3±2.21 in areas with 30 kg/ha and 6.1±1.91 in areas with 60 kg/ha fertilizer application. The mass of nodules was also greater in unfertilized areas: 91 g vs 63 g in 30 kg/ha and 50 g in 60 kg/ha fertilizer application. A similar decrease in number and mass of nodules per plant with fertilizer use was observed in the R3-R6 stage – 12.8±1.55 in areas without fertilizer and 10.3±2.31 in areas with 30 kg/ha fertilizer application and 8.1±1.97 in areas with 60 kg/ha fertilizer application. The mass of nodules was also greater in unfertilized areas – 91 g vs 63 g in 30 kg/ha and 50 g in 60 kg/ha fertilizer application. This observation is consistent with earlier observations that mineral nitrogen in the form of nitrate strongly inhibits the nitrogen fixation process during the later stages of the growth of the plants (Lin *et al.*, 2022). Thus, addition of inorganic nitrogen promotes growth and development during the early stages of growth of soybean plants. However, excess inorganic nitrogen in the soil suppresses the development of root nodules during later stages of growth.

As part of the research, an agrochemical analysis of the soil was carried out to determine the content of ammonia and nitrate nitrogen (Table 1). Fertilized plants showed a higher content of ammonia and nitrate nitrogen at all stages of plant growth and development. No significant difference in the content of nitrate nitrogen was found in unfertilized crops and fertilized soil between the V1-V3 and R1-R2 stages; however, a large drop in the nitrate nitrogen and ammoniacal nitrogen content of non-fertilized and fertilized soil was observed in the R3-R6 stage. This indicates that although soil must contain sufficient nitrogen during the early stages of plant development to enable proper development of photosynthetic apparatus, the amount of nitrogen absorbed from the soil is not much till the plants reach the bean formation stage. At this stage, the growing demand for nitrogen for seed protein synthesis is met by both absorption of large amounts of soil inorganic nitrogen and symbiotically fixed nitrogen. The ammonia nitrogen in the soil is increased in the flowering stage, most likely due to 'leakage' of symbiotically fixed ammoniacal form of nitrogen from the roots. Thus, it may be beneficial to apply a small amount of inorganic fertilizer (depending on soil nitrogen level) during the initial stages of soybean plant growth and then a larger amount at the later stages when the seeds are forming in the pods.

Effect of inter-row distance and the sowing rate on the number and weight of root nodules.

As part of the research, the influence of row spacing and seeding rate on the number and mass of root nodules per plant was determined for three soybean varieties. The seeds were sown in rows, with an inter-row distance of 15 cm (narrow-row sowing method) or 45 cm (wide-row sowing method) and at rates of 0.5 million, 0.6 million, 0.7 million, and 0.8 million seeds/ha. The average number of root nodules and active root nodules on the plants were determined in three varieties at R2 stage and the average data are presented in Figure 3. The narrow-row sowing method resulted in a greater number of nodules per plant on all three varieties. The number of nodules at 0.5 million seeds/ha was 26.3±4.6 for variety Ustya, 27.4±3.1 for variety Romantika, and 23.7±3.1 for variety Vorskla. An increase in seeding rate to 0.8 million/ha helped to increase the number of nodules to 27.5±2.6 in Ustya, 28.1±2.2 in Romantika, and 25.5±3.0 in Vorskla. For wide-row sowing method, the corresponding values were less by 4.5-10.6%.

The average mass of nodules on the plants was also determined in the three varieties. A greater mass of nodules was observed in plants grown with an inter-row spacing of 15 cm. At the seeding rate of 0.5 million seeds/ha, the average mass of nodules was 4.1±1.3 g in Ustya, 4.2±1.3 g in Romantika and 3.9±0.9 g in Vorskla variety. An increase in seeding rate to 0.8 million seeds/ha helped to increase the number of nodules to 4.3±0.9 in Ustya, 4.3±0.8 in Romantica, and 3.9±0.7 in Vorskla variety. For the wide-row sowing method, the corresponding values were 2.5-5.7% less. All data are presented in Figure 4.

Thus 15 cm inter-row distance and a seeding rate of 0.8 million seeds/ha resulted in the highest number and mass of root nodules per plant. The variety Romantica developed the highest number and mass of root nodules under optimal conditions. Effect of inter-row spacing and seeding rate on the nodule number and nodule mass per plant are variety and cultivation location dependent. In a study conducted on Merlin variety of soybean in Poland, the inter-row distance (15 cm or 30 cm) did not affect the nodule mass and number, whereas nodule mass and number showed a decreasing trend with the increasing seeding rate (70, 90, and 110 seeds/m^2) (Kaur, 2018; Kena, 2018). Similar results were obtained by testing the seeding densities from 40,000 to 320,000 seeds/ha in BRS 133 varieties of soybean (Natsumi *et al.*, 2019). At the same time, no correlation between the seeding rate or inter-row distance and the nodule number or nodule mass was found (Sobko *et al.*, 2019; Araujo *et al.*, 2018).

Effect of inter-row distance and seeding rate on the yield of soybean seeds.

The yields of soybean for crops cultivated at different inter-row distances and seeding rates are presented in Figure 5. The data from the third term crops were used to determine the effect of inter-row distance and seeding rate on the yields, as it more closely corresponds to real-world situation of a field being used for soybean cultivation for many consecutive years. A trend of increasing seed yield with the increasing seeding rate was observed in the crops cultivated using narrow-row sowing method at all sowing rates. In wide-row sowing method the seed yield increased from 0.5 to 0.7 million seeds/ha but dropped at 0.8 million seeds/ha by 6.1% in Romantika, 13.5% in Ustya, and 7.5% in Vorskla variety. Also, the difference in the seed yield between 0.7 and 0.8 million seeds/ha with the narrow-row sowing method, was small (2.9%, 4.3% and 3.2% for Romantika, Ustya, and Vorskla variety, respectively) which does not justify the extra expenditure for the purchase of extra 0.1 million seeds and the associated labor costs. Hence, a seeding rate of 0.7 million/ha was found to be optimum for both narrow-row and wide-row sowing method for all three varieties.

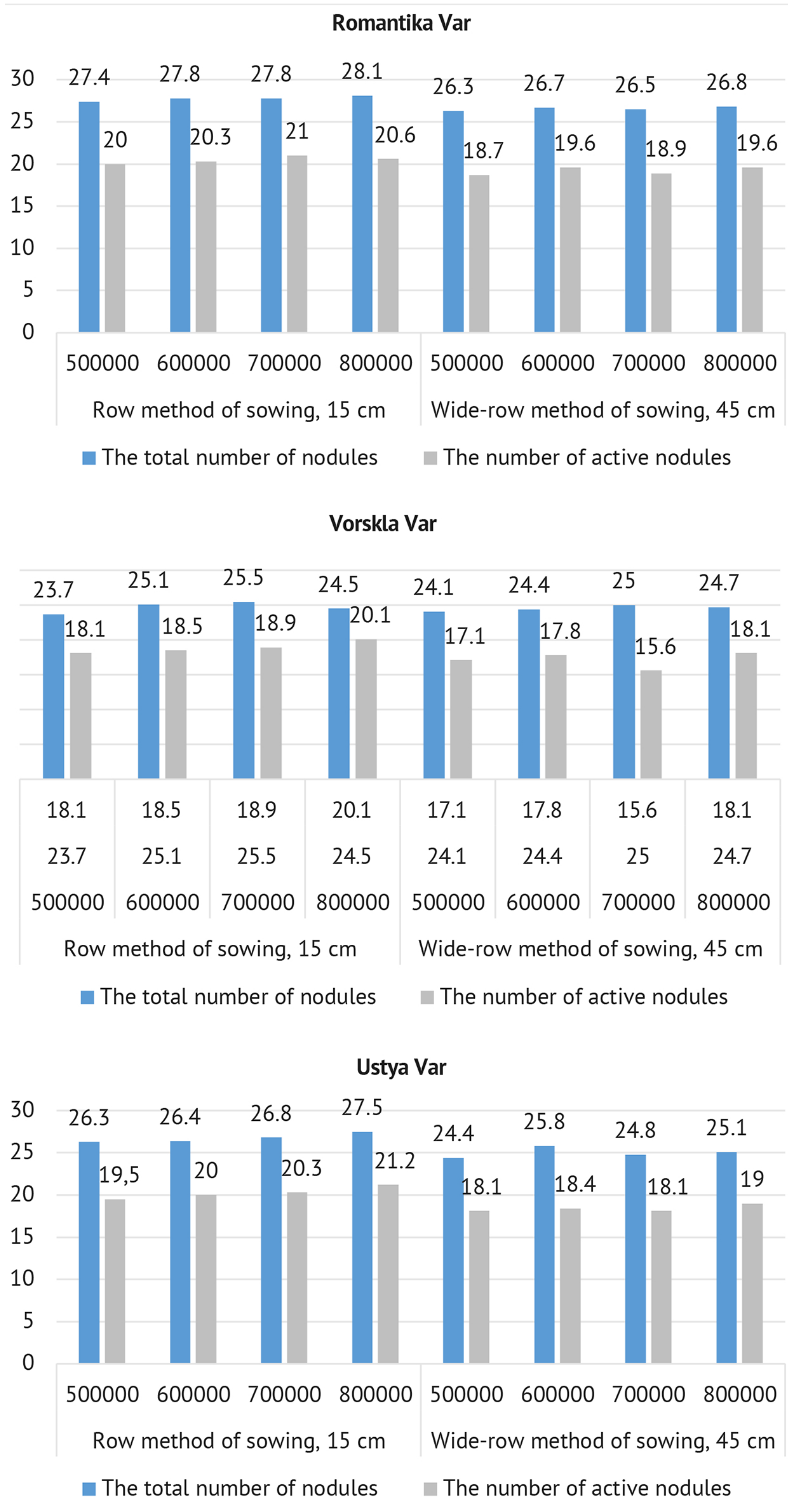

Figure 3. *The effect of variety, seeding rate and inter row distance plants on number of root nodules per plant in soybean plants*

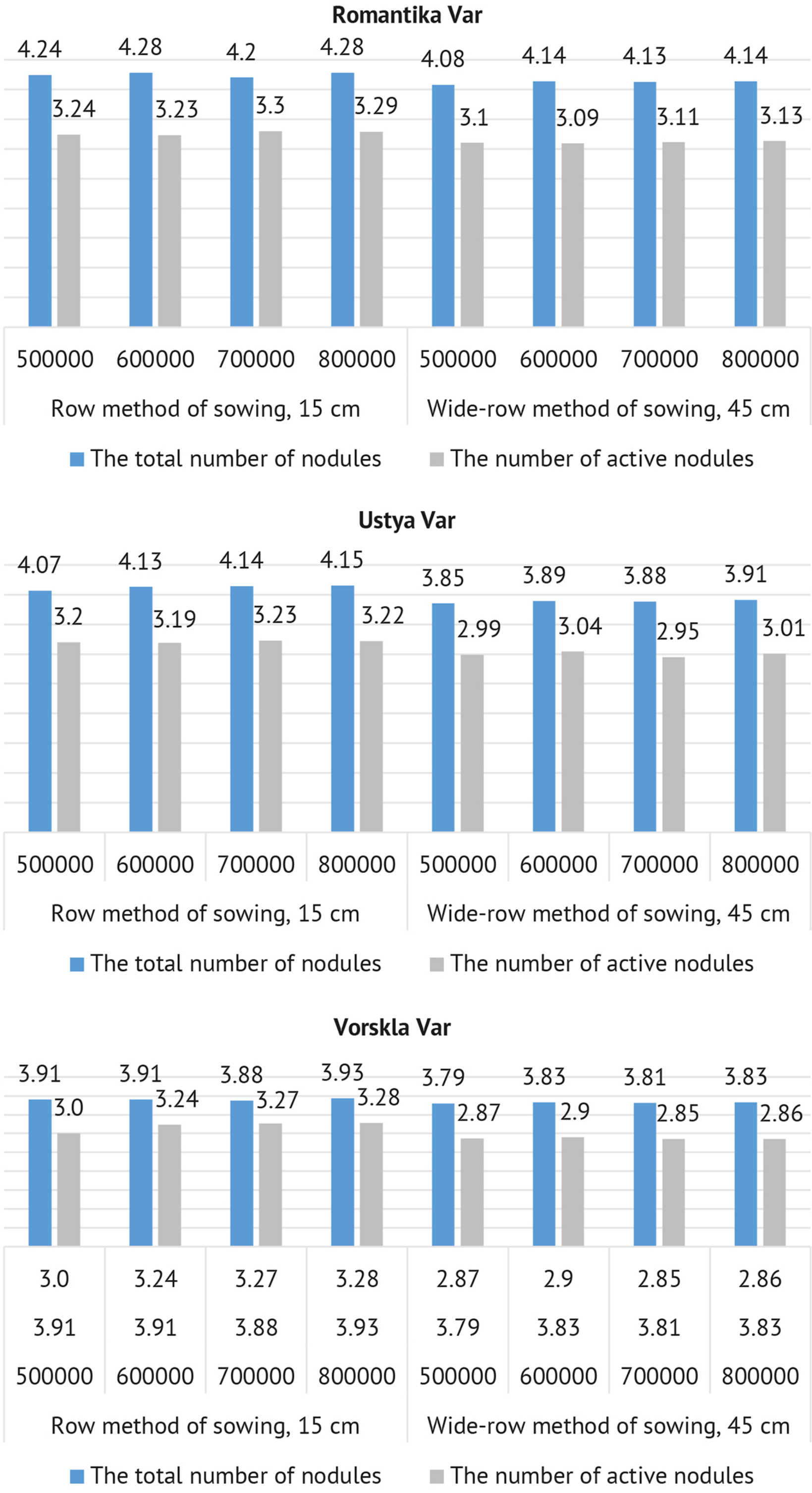

***Figure 4**. The effect of variety, seeding rate and inter row distance plants on mass of root nodules per plant in soybean plants*

At 0.7 million seeds/ha, the wide-row sowing method resulted in greater yield than the narrow-row sowing method by 21.0% for the Romantica, 19.6%, for the Ustya and 9.8% for the Vorskla variety. Under these conditions, the highest yield was obtained for Romantica variety at 2.95 t/ha (Fig. 5). Earlier studies have reported the effect of inter-row spacing and seeding rate on the seed yield in soybean. In the eastern Mediterranean region of Turkey, the highest yield in full-season crop was obtained at 50 cm and that in the late-season crop at 30 m row spacing (Weil & Brady, 2017). Mathenge, Thuita *et al.* obtained the highest seed yields at 25 cm row spacing in cultivar Ika in Siaya County of Kenya (Mathenge *et al.*, 2019; Leilah & Khan, 2021). A row spacing of 19 cm yielded 0.8-10% more seeds per hectare as compared to 76 cm row spacing in a study in South Dakota, USA. The highest yield was obtained at 506, 500 seeds/ha in this study (Vinnichek *et al.*, 2018). In another study in Western Ethiopia, the authors reported a different optimum inter-row spacing of 40, 50, and 60 cm for three different soybean varieties (Lyu *et al.*, 2019; Schutte & Nleya, 2019). It is likely that apart from the inter-row spacing, the performance of soybean crop is also affected by factors such as the variety, the local climatic conditions, and the properties of the soil, and the best seeding rate and inter-row spacing need to be determined for each soybean variety.

An inter-row spacing of 15 cm was optimal for root nodule development, but an inter-row spacing of 45 cm resulted in better seed yield in all three varieties.

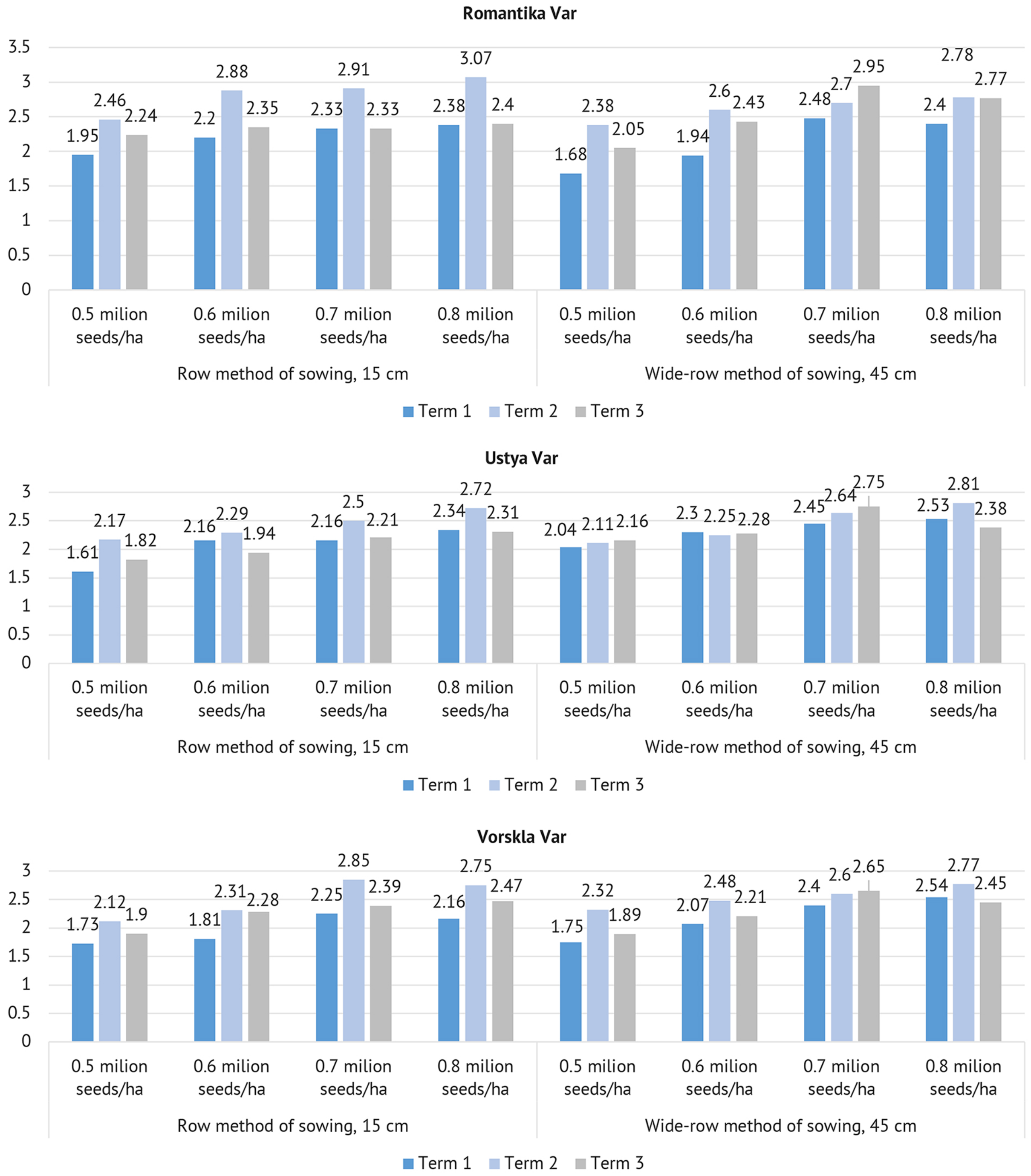

***Figure 5**. The effect of variety, seeding rate and inter row distance plants on mass of root nodules per plant in soybean plants*

The infection of root tissues with the symbiotic bacteria is mediated by the chemical mediators secreted by roots. The concentration of these mediators may be higher in the soil when more roots are present in a given area in narrow-row sowing. However, wide-row sowing may minimize the competition for soil resources and allow greater inception of light from different directions for photosynthesis (Schwember *et al.*, 2019; Ulafić *et al.*, 2020).

Thus, the increase in the rate of nitrogen fixation at the V1 and R1 stages at higher light intensity was due to greater growth and greater mass of nodules, and not to greater specific activity of the nitrogenase enzyme in the nodules.

This indicates that the amount of nitrogen absorbed from the soil is negligible until the plants reach the stage of bean formation, but it must be in sufficient quantity to ensure the proper development of the photosynthetic apparatus during the early stages of plant growth and development.

Also, the narrow-row method of sowing ensured a greater number and mass of nodules per plant, in all three varieties. There was also a tendency to increase seed yield with increasing seeding rate, so it can be concluded that 15 cm row spacing is optimal for the development of root nodules, but 45 cm row spacing resulted in better seed yield.

CONCLUSIONS

The effects of light intensity, soil inorganic nitrogen levels, seeding rate, and the inter-row distance on the biological nitrogen fixation efficiency and soybean seed yield were studied in three soybean varieties. The light intensity had a significant effect on the biomass accumulation in the nodules and the plants. The nodules accumulated significantly more biomass when grown at higher light intensity. The biological nitrogen fixation was also higher in the plants growing at the higher light intensity at all developmental stages before the ripening of the beans. Excessive fertilizer application was found to suppress the development and growth of nodules in the later stages and may thus affect the seed yield.

The sensitivity of soybeans to changes in the feeding area in the crop was studied. At optimal density, the main mass of beans is formed on the main shoot, in thinned ones – on side branches. Excessive thickening of litter leads to lodging, premature yellowing and falling of leaves on plants. Changing the sowing rate from 0.5 to 0.8 M seeds/ha for row sowing contributed to an increase in the attachment height of the lower beans, which, in turn, contributes to a reduction in crop losses during crop harvesting. The seeding rate and the inter-row distance affected the seed yield, and optimum levels of these parameters have been determined for the three varieties.

Sowing rate had a greater influence on soybean yield than the sowing method. The best conditions were obtained when sowing 0,7 M seeds/ha of similar seeds. Increasing the sowing rate to 0,8 M seeds/ha of similar seeds, especially for late sowing, did not contribute to a significant increase in yield. The early ripening Romantika variety had the maximum yield at the sowing rate of 0.7 M seeds/ha – 2.41 t/ha. Low sowing rates contributed to a decrease in seed yield to 2.07 t/ha – for sowing rates of 0.6 M seeds/ha & to 1.82 t/ha – for 0.5 M seeds/ha. Increasing the sowing rate to 0,8 M seeds/ha was ineffective – 2.39 tons/ha. The optimum growth conditions determined in this study for three soybean varieties will help farmers boost yields in the Romantica, Ustya, and Vorskla varieties of soybean.

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Вплив умов вирощування на азотфіксацію та врожайність насіння трьох українських сортів сої

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Анотація. Актуальність теми досліджень визначається пошуком нових технологічних прийомів вирощування сої. З огляду на це, досліджували особливості формування продуктивності різних сортів сої залежно від низки чинників, таких як: строки, способи сівби та норми висіву. Метою досліджень було теоретичне обґрунтування та практичні рекомендації щодо строків і способів сівби, норм висіву різних сортів сої. Проаналізовано показники впливу інтенсивності освітлення, внесення добрив, зміни норм висіву насіння та різних варіантів ширини міжрядь на біологічну азотфіксацію сої. В результаті встановлено закономірності та здійснено наукове обґрунтування положень, розроблено рекомендації виробництву та науково обґрунтовані прийоми технології вирощування сої, які забезпечують підвищення продуктивності культури на 15–25 %. Розроблені практичні рекомендації щодо збільшення виробництва сої використовуються в господарствах області та за її межами для вирішення важливої проблеми – збільшення виробництва кормового і харчового білка та рослинної олії. Зміна норми висіву з 0,5 до 0,8 млн насінин/га за рядкової сівби сприяла збільшенню висоти прикріплення нижніх бобів, що, в свою чергу, сприяє зменшенню втрат врожаю при збиранні культури. Норма висіву мала більший вплив на урожайність сої, ніж спосіб сівби. Найкращі умови були отримані при висіві 0,7 млн схожих насінин/га. В ході досліджень сорт Романтика показав найвищу врожайність 3,07 т/га за рядкового способу сівби, норми висіву 0,8 млн схожих насінин/га та другого строку сівби

Ключові слова: рослинництво, інтенсивність освітлення, строки сівби, норми і способи, кореневий бульбочок, міжряддя, норма висіву