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Pre-sowing seed treatment of soybean seeds as approach to increase crop yield

Soybean holds a leading position in the world ranking of the agricultural crops. The cultivated areas for this crop have been expanding in all countries of the global leaders in its production. In Kazakhstan, in recent years the cultivated areas have decreased from 139.5 thousand hectares in 2019 to 113.3 thousand hectares in 2021. This is due to the difficulty to grow the early-season varieties in the northern region of the Republic. The average crop yield of soybean by region ranges from 3.0 c/ha in the north to 24.8 c/ha in southeastern Kazakhstan. The crop yield of the developed and approved for production varieties can be increased by the additional agronomic techniques, including the pre-sowing seed treatment with the biologically active substances. This paper demonstrates the results of the effect of soybean seed treatment for different groups of maturity with the nitrogen-fixing inoculant HiStick and micronutrients of Co and Mo. Profitability of the conducted treatments was calculated. The pre-sowing treatment with salts of molybdenum and cobalt is profitable to use for early-season variety Ivushka and full-season variety Lastochka. For the early ripening variety Birlik KV, the highest profitability was observed for the combined seed treatment with nitrogen-fixing inoculant HiStick and salts of Mo and Co. In Zhansaya soybean variety, the application of the additional treatments decreases the profitability of production.

Keywords: soybean, variety, nitrogen fixation, micronutrients, crop yield, profitability.

Introduction

Significance of soybean in the global food system is indisputable. The unique qualitative seed composition, a wide range of product applications and green manure crop are priority for the agro-industrial complex of any country [1, 2]. The cultivated areas in the Republic of Kazakhstan tend to spread the area for this crop. In 2021, about 113.3 thousand hectares were for the crop [3]. The main soybean are in the Republic is its southeastern region — the Almaty region. This region is an irrigated area. About 15 thousand hectares are occupied by soybean in the north and east of Kazakhstan in Kostanay and East Kazakhstan regions. These regions are cultivated without irrigation. The high soybean crop yield of 30-35 c/ha in the south-east of Kazakhstan is resulted by the favorable climatic conditions, many warm days, cultivation of the mid-season with middle-late varieties, a growing season of 120-140 days and irrigation. In the northern and eastern regions, the crop yield of varieties is low and less than 10-15 c/ha. This is due to less positive temperatures, cultivation of the early-ripening varieties, and lack of irrigation.

The highest soybean crop yields with high quality factors depend on the regular, balanced plant nutrition by the macro- and micronutrients. This is due to the fact that intensification of the agriculture increases in removal of all nutrients including micronutrients [4].

Micronutrients improve nitrogen fixation. Thus, the molecular nitrogen fixation in legume nodules depends on a complex of micronutrients in various enzymes [5]. Therefore, it is important to study the effect of the certain micronutrients on the symbiotic fixation of the molecular nitrogen by soybean. Their nutrition will be improved due to the atmospheric nitrogen. As a result, the biological cycle will include the additional nitrogen inaccessible to other crops.

Some experiments in our country and abroad have proved that the biological nitrogen significantly enhances soybean crop yield and a protein in seeds without reducing an oil content, i.e. it is very important [6–8]. In the grain legume group, soybean and white lupine have the highest nitrogen-fixing activity [9].

In order to cultivate soybean an obligatory and important approach is an application of the bacterial fertilizer (rhizotorfin) containing an active strain of the nodulating nitrogen-fixing bacteria [10, 11].

The seed treatment by nitrogen-fixing inoculants, foliar nutrition with preparations containing biologically active substances [12, 13], stimulants and regulators of growth [14-16], various types of the microbio-

logical fertilizers [17-21] are becoming very popular. Studies demonstrate the positive effects from these types of stimulants.

Cobalt and molybdenum are the most important of all micronutrients in the nitrogen fixation process [22-25]. Cobalt elevates the leghemoglobin content in nodules. Its content determines intensity of their respiration. The nitrogen fixation process is active with cobalt. Molybdenum is a component of about 20 enzymes. It is actively involved in protein and phosphorus metabolism. It affects intensity of respiration and chlorophyll synthesis. Choice of method and practicability of molybdenum application in soybean cultivation should be very carefully, i.e. the pre-sowing treatment can reduce soybean crop yield during the high content of this micronutrient in seeds. The simplest method of providing soybean with this element is the pre-sowing seed treatment. Thus, it is possible to increase nitrogen fixation and to achieve 10-15 % of the crop yield increase [22].

Not all soybean varieties are well adoptive to the pre-sowing treatment with cobalt and molybdenum, i.e. it may be related to their growing season [26]. However, it has been stated that the pre-sowing treatment with micronutrients has an impact on the complex of production characters [27].

Purpose of the study is to determine the possibility of yield increase of the domestic soybean varieties using cobalt and molybdenum salts in combination with a nitrogen-fixing inoculant.

Experimental

The studies were conducted in 2020-2021 in the experimental field sites of laboratory of oilseeds at LLP “Kazakh Research Institute of Agriculture and Plant Growing”, in the Almaty region.

Four soybean varieties of different groups of maturity were studied for the pre-sowing seed treatment: Lastochka (III), Zhansaya (II), Birlik KV (0) and Ivushka (00).

The day before the sowing, the soybean seeds were treated with ammonium molybdate 4 % w/v aqueous solution (40 g per 100 kg of seeds) and cobalt (II) sulfate heptahydrate (4 g per 100 kg of seeds). On the day of the sowing, seeds were inoculated with HiStick containing nitrogen-fixing bacteria (400 g per 100 kg of seeds). The experiment was according to the scheme: the control — without treatment; the first experience — seed treatment with HiStick; the second experience — seed treatment with Mo + Co; and the third experience — seed treatment with HiStick + Mo + Co.

The sowing was done in the third decade of April. The registration plot was 25 m^2. The seeding rate was 500 thousand pcs/ha. The row spacing was 30 cm. The depth of seed placement was 4 cm.

The randomized seeding was replicated four times. The agrotechnological actions were made with the standard methods and recommendations for the research area [28]. Establishment of experiments, harvesting and crop accounting was performed with the method of field study of Dospekhov B.A. [29]. The structural analysis was performed under the VIR procedure [30]. The vegetative irrigation was done three times in the development phases (flowering, full pod, full seed) on June 15-20, July 10-15 and August 10-15 with an irrigation rate of 1200 m^3/ha.

The statistical processing was performed in the open-source R (https://cran.r-project.org/) software and in the Windows Excel program.

The weather conditions in 2020 were comparable to the mean annual values. However, decrease in moisture availability in May, June and July was observed. Conditions in 2021 differed significantly from the mean annual indicators, i.e. they were arid. In 2021 the temperature was 1.2-2.9 ^{0}C higher than the average annual indicators. July was the hottest month, with a deviation of 2.9 ^{0}C from the average annual indicators. Maximum day temperatures of 20 days of this month were in the range of 35-39 ^{0}C. The amount of precipitation during the growing season in 2021 was 1.5 times lower than the average annual indicators. The decrease in precipitation was observed in all spring and summer months (Fig. 1).

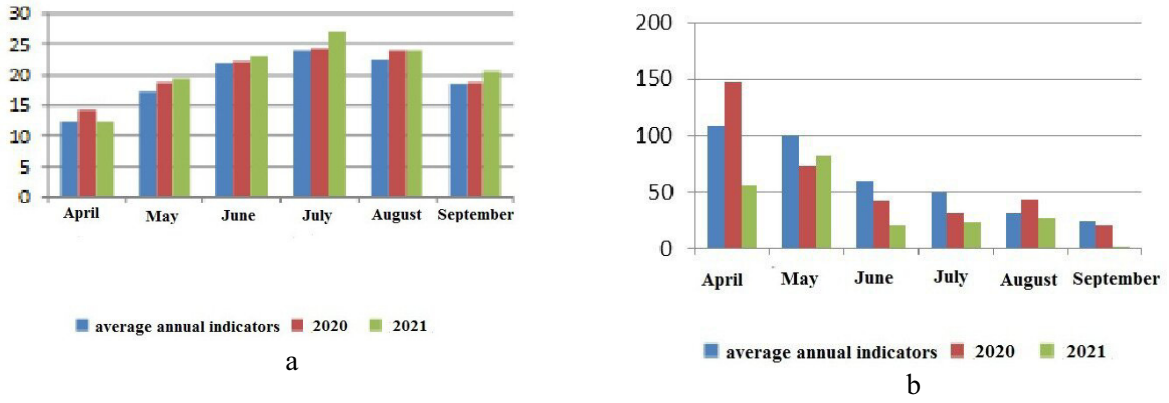

Figure 1. Distribution of temperature (*a*) and precipitation (*b*) in experimental area for 2020 and 2021

Results

The phenological observations demonstrated some variations from year to year within one variety. However, different types of treatments did not impact on the individual development phases. All varieties in the control and with treatments ripened within their group of maturity. The growing season of varieties of Ivushka was 95-97 days, Birlik KV — 107-110 days, Zhansaya — 127-130 days and Lastochka — 139-145 days.

The soybean crop yield of varieties has a positive correlation with the group of maturity (r = 0.87). It is interesting to state that weather conditions had an ambiguous effect on the crop yield of varieties of groups of maturity. During the driest year the crop yields of soybean varieties of Birlik KV and Zhansaya were decreased. The late-ripening variety Lastochka had higher crop yield compared to 2020 (Fig. 2).

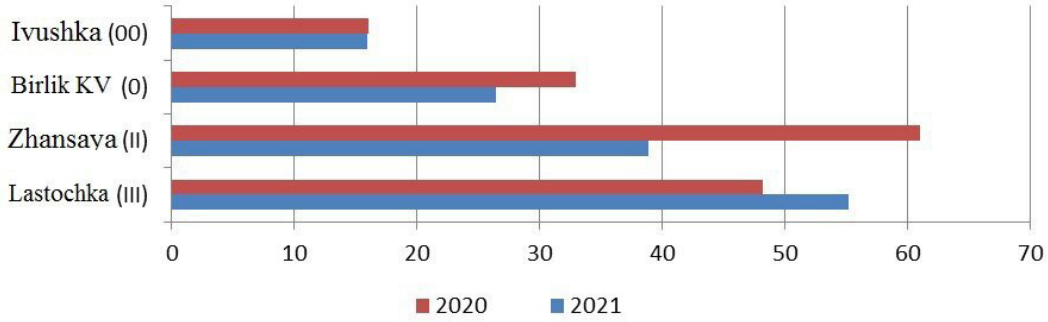

Figure 2. Soybean crop yield of varieties of the four groups of maturity during the study years, c/ha

The pre-sowing seed treatment showed varietal specificity for the types of treatment. Thus, the average crop yield of the early ripening of variety Ivushka was the lowest. The crop yield depending on treatment was in the range from 15.5±1.0 c/ha to 16.9±0.5 c/ha. This variety had the smallest range of variability in crop yield as compared to the full-season varieties. The second highest crop yield was middle-early variety Birlik KV with values from 28.8±3.8 c/ha to 31.7±3.4 c/ha. Soybean varieties of maturity groups of II and III were the most yielding. The crop yield of variety Zhansaya during the study years averaged 50.0±9.3 c/ha — 51.8±12.8 c/ha. The crop yield of the most late-ripening variety Lastochka was 48.5±1.6 c/ha — 54.8±5.1 c/ha. The crop yield of ultra-ripening variety Ivushka and late-ripening variety Lastochka most impacted by the pre-sowing treatment with micronutrients of Mo and Co without nitrogen-fixing inoculant. The crop yield increase compared to the control for these varieties was 1.4 and 6.3 c/ha, respectively.

The crop yield of early-ripening variety Birlik KV and mid-season variety Zhansaya significantly increased by 2.3 c/ha and 1.8 c/ha with a combined treatment of seeds with nitrogen-fixing inoculant HiStick and micronutrients of Mo and Co (Table 1).

Table 1

Soybean crop yield of four groups of maturity with various types of the pre-sowing seed treatment, c/ha

Types of treatments	2020	2021	Average	Deviations from the control
Ivushka (00)				
The control	16,5±2,5	14,5±2,9	15,5±1,0	0,0
HiStik	14,6±1,7	15,0±1,0	14,8±0,2	-0,7
Mo, Co	16,3±4,4	17,4±5,9	16,9±0,5	1,4
HiStik+ Mo, Co	16,7±3,1	16,7±0,4	16,7±0,0	1,2
HCP	*1,77*	*1,25*		
Birlik KV (0)				
The control	34,1±3,3	24,6±7,7	29,4±4,8	0,0
HiStik	32,5±3,5	25,0±7,1	28,8±3,8	-0,6
Mo, Co	30,0±4,8	27,7±1,7	28,8±1,2	-0,6
Histik+ Mo, Co	35,1±4,2	28,3±6,1	31,7±3,4	2,3
HCP	*2,12*	*1,88*		
Zhansaya (II)				
The control	59,2±9,2	40,7±4,4	50,0 ±9,3	0,0
HiStik	61,4±9,6	40,6±2,9	51,0±10,4	1,0
Mo, Co	58,9±5,2	35,3±8,5	47,1±11,8	-2,9
HiStik + Mo, Co	64,6±7,1	39,0±4,0	51,8±12,8	1,8
HCP	*1,55*	*2,14*		
Lastochka (III)				
The control	46,9±4,2	50,0±4,2	48,5±1,6	0,0
HiStik	46,4±2,7	56,9±6,3	51,7±5,3	3,2
Mo, Co	49,7±6,9	56,9±6,3	54,8±5,1	6,3
HiStik + Mo, Co	49,9±1,9	56,9±2,1	53,4±3,5	4,9
HCP	*1,99*	*1,85*		

Production costs of the test sowing consist of the seed cost, salary fund of mechanics, irrigators, agronomist, including all taxes, the cost of fuel and lubricants, fertilizers, amortization, overhead costs, cost of irrigation water, storage, cleaning and storage of seeds.

For the additional types of treatments, production costs increase from the cost of nitrogen-fixing inoculant and micronutrients, and expenditures of the seed treatment. Minimum increase in production costs involves the using of micro-fertilizers and it is 1.63 US dollars. Application of nitrogen fixing inoculant increases production costs by 22.88 US dollars per hectare. Application of the HiStik + Mo, Co complex magnifies the costs by 24.51 US dollars.

Calculation of the economic efficiency proves the high profitability of soybean production. Thus, the early ripening and low-yielding variety Ivushka has profitability of 39.3-64.8 %. The full-season and high-yielding variety Lastochka had profitability of 374.3 — 434.4 % depending on treatment.

Soybean seed treatment of the ultra-ripening variety Ivushka with nitrogen-fixing inoculant HiStik for two study years showed the low efficiency. In the first year with this type of treatment, the crop yield of Ivushka variety was lower than in the control. In the second year it did not significantly exceed in the control. Thus, this type of treatment was the least profitable (39.3 %). The using of the pure salts of molybdenum and cobalt were the most profitable (64.8 %) for this variety.

Application of the Histik + Mo, Co complex was the most cost-effective for early-ripening variety Birlik KV in production. Profitability of this production was 197.5 %.

The highest profitability for the mid-season soybean variety Zhansaya was observed in the control. However, the using of nitrogen-fixing inoculant HiStik in combination with Mo and Co in the pre-sowing seed treatment resulted in a yield increase of 1.8 c/ha. The additional costs for these inoculants reduced the overall profitability from 388.9 to 386.2 % (Table 2).

The good results were obtained for the late-ripening variety Lastochka. Its profitability was higher than in the control during any type of treatment. The seed treatment with micronutrients of molybdenum and cobalt had the highest profitability. Profitability of this type of treatment in variety Lastochka was 434.4 %, and 374.3 % in the control.

Table 2

Calculation of the economic efficiency

Types of treatment	Production costs per hectare, US dollars	Crop yield, c/ha	Price of 1 ton of commercial seeds, US dollars	Cost of gross production from 1 ha, US dollars	Conditional net income from 1 ha, US dollars	Profitability, %
Ivushka						
The control	584,96	15,50	572,00	886,60	301,64	51,6
HiStik	607,84	14,80	572,00	846,56	238,72	39,3
Mo, Co	586,59	16,90	572,00	966,68	380,09	64,8
HiStik + Mo, Co	609,47	16,70	572,00	955,24	345,77	56,7
Birlik KV						
The control	584,96	29,40	572,00	1681,68	1096,72	187,5
HiStik	607,84	28,80	572,00	1647,36	1039,52	171,0
Mo, Co	586,59	28,80	572,00	1647,36	1060,77	180,8
HiStik + Mo, Co	609,47	31,70	572,00	1813,24	1203,77	197,5
Zhansaya						
The control	584,96	50,00	572,00	2860,00	2275,04	388,9
HiStik	607,84	51,00	572,00	2917,20	2309,36	379,9
Mo, Co	586,59	47,10	572,00	2694,12	2107,53	359,3
HiStik + Mo, Co	609,47	51,80	572,00	2962,96	2353,49	386,2
Lastochka						
The control	584,96	48,50	572,00	2774,20	2189,24	374,3
HiStik	607,84	51,70	572,00	2957,24	2349,40	386,5
Mo, Co	586,59	54,80	572,00	3134,56	2547,97	434,4
HiStik + Mo, Co	609,47	53,40	572,00	3054,48	2445,01	401,2

Conclusions

1. The soybean production is highly profitable.
2. The increase in profitability of production from ultra-ripening to late-ripening varieties was observed.
3. The pre-sowing seed treatment determined the varietal response to application of stimulants.
4. It was the most cost-effective to use the pre-sowing treatment with salts of molybdenum and cobalt for varieties of Ivushka and Lastochka. The highest profitability was observed in the combined seed treatment with nitrogen-fixing inoculant HiStick and salts of Mo, Co for the variety Birlik KV. Application of the additional treatments reduced the profitability of production in Zhansaya soybean variety.

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Өнімділікті арттыруға тәсіл ретінде соя тұқымдарын алдын ала өңдеу

Соя ауыл шаруашылығы дақылдарының әлемдік рейтингісінде алдыңғы орында. Осы дақылдарды өндіру бойынша өсірілетін алаңдар әлемдік көшбасшылардың барлық елдерінде кеңейіп келеді. Қазақстанда соңғы жылдары өңделетін алқаптар 2019 жылғы 139,5 мың гектардан 2021 жылы 113,3 мың гектарға дейін қысқарды. Бұл республиканың солтүстік ауданында ерте маусымдық сорттарды өсірудің қиындығымен байланысты. Өңірлер бойынша сояның орташа өнімділігі солтүстікте 3,0 ц/га-дан Қазақстанның оңтүстік-шығысында 24,8 ц/га-ға дейін ауытқиды. Өндіріс үшін әзірленген және бекітілген сорттардың өнімділігі қосымша агрономиялық әдістермен, оның ішінде тұқымдарды биологиялық белсенді заттармен алдын ала себу арқылы ұлғайтылуы мүмкін. Мақалада соя тұқымдарын өңдеудің әр түрлі жетілу топтары үшін азот жинақтаушы HiStick иннокулят пен Со және Мо микроэлементтерімен әсер ету нәтижелері көрсетілген. Жүргізілген өңдеулердің рентабельділігі есептелген. Молибден және кобальт тұздарын себу алдындағы өңдеуді ерте маусымдық «Ивушка» сорты және толық маусымдық «Ласточка» сорты үшін пайдалану тиімді. Ерте пісетін «Birlik KV» сорты үшін тұқымдарды азот жинақтаушы HiStick иннокулят пен Со және Мо тұздарымен біріктіріп өңдеу кезінде ең жоғары рентабельділік байқалды. Ал «Жансая» соясының сорттарында қосымша өңдеулерді қолдану өндірістің рентабельділігін төмендетеді.

Кілт сөздер: соя, сорттар, азот жинақтаушы, микроэлементтер, түсімділік, кірістілік.

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Предварительная обработка семян сои в качестве подхода к повышению урожайности

Соя занимает лидирующие позиции в мировом рейтинге сельскохозяйственных культур. Возделываемые площади по производству этой культуры расширяются во всех странах мировых лидеров. В Казахстане за последние годы обрабатываемые площади сократились со 139,5 тыс. га в 2019 г. до 113,3 тыс. га в 2021 г. Это связано с трудностью выращивания ранне-сезонных сортов в северном районе Республики. Средняя урожайность сои по регионам колеблется от 3,0 ц/га на севере до 24,8 ц/га на юго-востоке Казахстана. Урожайность разработанных и утвержденных для производства сортов может быть увеличена дополнительными агрономическими методами, в том числе путем предварительной посевной обработки семян биологически активными веществами. Настоящая статья демонстрирует результаты воздействия обработки семян сои для различных групп зрелости азотфиксирующим инокулятом HiStick и микроэлементами Со и Мо. Рассчитана рентабельность проведенных обработок. Предпосевную обработку солями молибдена и кобальта выгодно использовать для ранне-сезонного сорта «Ивушка» и полно-сезонного сорта «Ласточка». Для сорта раннего созревания «Birlik KV» наибольшая рентабельность наблюдалась при комбинированной обработке семян азотфиксирующим инокулятом HiStick и солями Мо и Со. В сортах сои «Жансая» применение дополнительных обработок снижает рентабельность производства.

Ключевые слова: соя, сорт, фиксация азота, микроэлементы, урожайность, доходность, предпосевная обработка.

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