RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
57 (4) 1625-1633, 2025
http://doi.org/10.54910/sabrao2025.57.4.28
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

EFFECTIVENESS OF FOLIAR FERTILIZATION WITH AMINO ACIDS AND HUMIC FERTILIZERS IN WINTER WHEAT AND SOYBEAN UNDER LOW-FERTILITY SOILS

R. RAMAZANOVA, M. ZHUMAGULOVA*, S. TANIRBERGENOV, and T. SHARYPOVA

Uspanov Kazakh Research Institute of Soil Science and Agrochemistry, Almaty, Kazakhstan
*Corresponding author's email: zhumagulova.mk@mail.ru
Email addresses of co-authors: raushasoil88@mail.ru, samat.soil.kz@gmail.com, sharipovatat@mail.ru

SUMMARY

The priority of agricultural development is to ensure a significant increase in crop yields while improving soil fertility through the use of fertilizers and reducing the ecological burden on the environment. The following study sought to assess the role of foliar fertilization with amino acid (Amino Turbo) and humic acid (Ruter AA and Geogumat) fertilizers on the grain yield of winter wheat (*Triticum aestivum* L.) and soybean (*Glycine max* L.). Field experiments conducted during 2023–2024 focused on the low-fertility soil, lightly irrigated sierozems, with phosphorus fertilizers as a baseline in the District Koksu, Zhetysu Region, Kazakhstan. Fertilizations occurred at key development phases, i.e., the first at BBCH (cereal development stage scale) 25–29 and the second at BBCH 30–31. Without foliar fertilizers, average yields were 3.26 t/ha in winter wheat and 3.07 t/ha in soybean. Ruter AA yielded the best result in winter wheat (4.64 t/ha), while Geogumat improved the soybean yield (4.13 t/ha). Amino Turbo was ineffective in winter wheat; however, it increased the soybean yield relative to the control. The combined application of humic and amino acid fertilizers with phosphorus supported 68%–84% yield potential in winter wheat and 92%–98% in soybean, maintaining optimal soil nutrient levels (20–40 mg/kg in wheat and 25–40 mg/kg in soybean). Overall, the humic acids (Ruter AA and Geogumat) significantly enhanced the yield potential, revealing the efficiency of this nutrient strategy for better plant growth and productivity.

Keywords: Winter wheat (*Triticum aestivum* L.), soybean (*Glycine max* L.), humic acids, amino acids, leaf fertilizers, mobile phosphorus, growth traits, grain yield

Key findings: The water deficit condition at the flowering stage caused a significant reduction in yield and its components in maize. The silicon treatment 6 mM L^{-1} concentration notably enhanced the grain and oil yields and carbohydrates.

Communicating Editor: Dr. Gwen Iris Descalsota-Empleo

Manuscript received: November 02, 2024; Accepted: February 08, 2025.

Citation: Ramazanova R, Zhumagulova M, Tanirbergenov S, Sharypova T (2025). Effectiveness of foliar fertilization with amino acids and humic fertilizers in winter wheat and soybean under low-fertility soils. *SABRAO J. Breed. Genet.* 57(4): 1625-1633. http://doi.org/10.54910/sabrao2025.57.4.28.

INTRODUCTION

Environmental risks associated with the use of mineral fertilizers, and their high cost and sometimes shortage, encourage the farming community to search for alternate sources of fertilizers and nutrition for crop plants. In previous years, interest in fertilizers containing humic and amino acids has progressed. These organic compounds can be useful as a promising tool in the current scenario of crop production, which can promote plant growth under various environmental stresses and help achieve the maximum potential yield with minimum synthetic fertilizer use (Bhupenchandra *et al*., 2020; Arslan *et al*., 2021). The application of such fertilizers can supplement traditional mineral nutrition schemes with maximum positive effects (Du-Jardin, 2015; Van-Oosten *et al*., 2017).

Crop fertilization with humic and amino acids enhances the plants' resistance to stress factors, such as temperature, water, light, salt, soil, and pesticide (Shapoval *et al*., 2018). These organic compounds also activate photosynthesis processes by increasing the chlorophyll level in plant leaves, improving plants' ability to assimilate more nutrient elements (Forde and Lea, 2007), and boosting the resistance to pests and diseases (Yang, 2005; Howe and Jander, 2008). Moreover, amino acids play a vital role in the processes of pollen fertility and fruit ovary formation (Borghi and Fernie, 2017).

Based on D.N. Pryanishnikov's theory of mineral nutrition, and agrochemical scientists' claim that amino acids, sugars, sucrose phosphates, and other organic compounds can be beneficial in insignificant quantity in plant nutrition, they further suggest the possibility of heterotrophic type of nutrition in crop plants with the assimilation of organic compounds (Yagodin *et al*., 1989). Clearly, it is impossible to replace the basic type of nutrition, as it will lead to the disruption of metabolic processes; however, it is possible to use small amounts of natural activators as an emergency aid (Wilczewski *et al*., 2018; Dass *et al*., 2022; Islam *et al*., 2024).

Leaf organic-mineral fertilizers can be effective in smaller doses, which are also less susceptible to leaching from the root-inhabited layer of soil, and thus, reducing the negative impact on the environment (Trevisan *et al*., 2010). By applying leaf fertilizers, it is crucial to consider the timing of their application. Studies showed their implementation at early stages of growth and development contributes to better performance of the root system, enhancing photosynthetic activity (Shafran, 2020).

In the nutrition of winter wheat (*Triticum aestivum* L.) and soybean (*Glycine max* L.) plants, the farmer's approach does not always include the physiological requirements of the crop for nutritional elements. In the fertilizer system, it is necessary to introduce the essential elements at the stage of producing generative organs as the basis of future yield. The winter wheat yield depends on the provision of plants with nutritional elements, especially during the period of formation and development of reproductive organs, which falls in the fall-early spring period. It corresponds to the tillering phase; at this stage, wheat intensively builds up vegetative mass and needs a lot of nitrogen to form stems and leaves. The tillering stage also plays an influential role in the production of grain yield. The more shoots laid at this stage, the higher the productivity of the crop will be. Early foliar feeding helps to compensate for stressful conditions (low temperatures, lack of moisture), recover from the winter period, and support the intensive growth of vegetative mass. The next stage responsible for the formation of the ears is the IV stage of organogenesis. During this period, intensive plant growth, spikelet initiation, and creation of the number of grains continue.

The determination of soybean nutrition appears by its ability to fix atmospheric nitrogen due to the vital activity of nodules' bacteria. In this case, a necessary condition is the pre-sowing seed treatment with active strains of corresponding microorganisms. However, solving the problem of nitrogen nutrition results in applying mineral nitrogen. At the very initial stage of development (the stage of seed germination or stage I of organogenesis), the management of nitrogen needs comes from the seeds' reserve substances. The first leaf feeding of soybean corresponds to the appearance of the third triple leaf (III stage of organogenesis). At this stage is a lying of generative organs, active growth of vegetative mass, formation of new shoots, and development of leaf apparatus. Foliar fertilization meets the need for nitrogen and trace elements required for biomass growth and photosynthetic activities (Negrea *et al.,* 2022; Bărdaş *et al.,* 2023).

An excess of mineral nitrogen can reduce the number of laid flowers and delay their formation. The second leaf feeding of soybean corresponds to the budding-flowering phase (IV-V stages of organogenesis), during bud formation and at the beginning of the generative period. Flower buds appear on plants, preparing plants to begin flowering. However, an active consumption of phosphorus and potassium happens, which also play a crucial role in stimulating the flowering and formation of generative organs. In soybeans, it is critical to develop a phosphorus-potassium background by the application of fertilizers, preferably ammophos and potassium sulfate.

Traditional feeding only with nitrogen fertilizers is not always effective because the plant needs microelements, organic compounds, and biostimulants. This justifies the fact that fertilizers with a set of additional components, including humic acids and amino acids, enhance the availability of nutrient elements regardless of the degree of soil availability. Likewise, this allows avoiding temporary deficiency of nutritional elements and supports the normal plant development.

The introduction of fertilizer application protocol based on foliar feeding in the early phases of development of winter wheat and soybean can have a positive effect on stress tolerance and environmental factors by reducing the load of agrochemicals in the fields, thus providing flexibility in the fertilizer application system and a reliable tool in the strategy of yield management on low-fertility, light sierozem. In this regard, the promising research sought to evaluate the effectiveness of foliar fertilization with humic and amino acids in winter wheat and soybean and confirm their role in supplying plants with nutrients and increasing yields on low-fertility soil, irrigated light sierozem soils in the southeastern region of Kazakhstan.

MATERIALS AND METHODS

Site description and experimental design

Field experiments transpired during 2023–2024 in the fields of the "Kainar Koksu" P.F. in the District Koksu, Zhetysu Region, Southeastern Kazakhstan (44°88349398″N 78°11644999″E) (Figure 1).

The study area climate has a continental classification. According to the meteorological station in Taldykorgan (45°01′39″ N, 78°26′15″ E), in January the average temperature ranges from -9 °C to -7 °C and was the coldest month, while July sees temperatures between 22 °C and 24 °C and was the hottest month of the cropping season. In some locations, winter temperatures can plummet to -35 °C. For 2023–2024, the annual precipitation ranged from 400.1 to 468.3 mm, with an average annual air temperature of 9.4 °C and 16.3 °C during the growing season. Irrigation occurred in crop cultivation, and under the experimental conditions, the water availability was not a limiting factor.

Field experiments started on arable plots of the crop farm, laid out in a randomized complete block design (RCBD) with three replications, following the field experiment methodology of Dospehov (2011). The experimental methodology has become widely used in agronomy and other related sciences to study the cultivated plants along with the soil-climatic and agro-technical factors. It also complies with methodological requirements: specialty of the experiment, observance of the principle of a single difference, conducting the experiment on a specially allocated plot, yield accounting, and reliability of the experiment in essence. Each experimental unit plot covered an area for winter wheat (96 m² - 8 m × 12 m) and soybeans (150 m² - 10 m × 15 m), with at least one meter of spacing for protection between the plots and replications preventing fertilizer contamination mixing. The different treatments used were control (no fertilizers), phosphorus fertilizer (background),

Figure 1. Location of the experimental fields and placement of their test sites.

P (background) + Amino Turbo (amino acid), P (background) + Ruter AA, and P (background) + Geogumat.

Two weeks before sowing of winter wheat (in August 2022 & September 2023) and soybean (in April 2023 & 2024), phosphorus fertilizer application to the soil ensued in accordance with the availability of these elements in the soil (120 kg per ha^{-1} in winter wheat and 94 kg ha^{-1} in soybean). The fertilizer used had the form of mono-ammonium phosphate (MAP—10%–12% N, 52% P_2O_5). Before experimenting, the plots designated for field trials bore assessment for the available mobile forms of nutrients. This assessment was necessary to calculate the phosphorus fertilizer rates using the balance method while considering the soil's content of mobile nutrient forms.

The experimental design included various test plots utilizing humic acids and amino acids for double foliar treatment during the III (BBCH 25-29) and IV-V (BBCH 30-31) stages of organogenesis. The extended BBCH scale is a system for a uniform coding of phenologically similar growth stages of all mono- and dicotyledonous plant species (Meier, 2018). The treatment of humic acids and amino acid fertilizers was according to the manufacturer's recommendations.

Object of the study

The study used the winter wheat cultivar Bezostaya-100, which was bred at the National Grain Centre, named after P.P. Lukyanenko, Russia. The said variety's classification was medium-early, with a growth duration of 221 to 296 days and a yield of 5.0 to 6.0 t/ha. The cultivar Bezostaya-100 easily shatters and damages, and it exhibits drought and heat tolerance (https://ooopchelka.ru). The soybean cultivar Zhansaya (originator Kazakh Research Institute of Agriculture and Crop Production, RK) was the sample soybean. The said cultivar belongs to the group of medium-ripening (I group of ripeness), with a vegetation period of 120–125 days, potential grain yield of 3.9 to 4.5 t/ha, and no lodging. Beans ripen at the same time, do not crack, the grain does not crumble, and with the plant height of 95–105 cm (https://kazniizr.kz). The experiments used the following fertilizers: Ammonium nitrate, Monoammonium phosphate, Amino Turbo (powder), *Ruter AA (liquid),* Geohumate (powder).

Research methods

The collection of soil samples came from each experimental plot at 0–20 and 20–40 cm depths. Sample preparation involved drying of the samples, grinding them in a soil mill, and passing them through sieves with one and 0.25 mm sizes. Soil analysis included the determination of humus content according to Tyurin, the content of easily hydrolyzable nitrogen (the nitrogen from easily mineralizable organic compounds) extraction using a sulfuric acid solution, and the mobile forms of phosphorus and potassium in carbonate soils. This was successful by extracting mobile compounds with a 1% ammonium carbonate solution at a pH of 9.0. Additionally, the pH of the water extract succeeded in measuring ionometrically, with the granulometric composition assessed using the N. Kachinsky pipette method.

The experiment took place on light sierozem soils of medium loam and loess loams, typical for the region. During the research, the pH (8.54) of the water extract appeared to be slightly alkaline (Table 1). The soil has characteristics of a shallow content of humus and easily hydrolyzable nitrogen, averaging between 0.57% and 1.11% and 22.4 to 33.6 mg/kg, respectively. The phosphorus content ranged from very low to average, with an average of 10.0 to 18.0 mg/kg. The exchangeable potassium levels varied from low to average, averaging between 200 and 260 mg/kg. Considering the soil availability data, we calculated the norms of phosphorus-potassium fertilizers under the main application to create a background, and the norms of phosphorus fertilizers under crops on average were 119 kg a.i./ha for winter wheat and 94 kg a.i./ha for soybean. The regulation of nitrogen nutrition levels employed the treatment on vegetative plants during the early stages of growth and development.

Statistical analysis

The experiments transpired within the system integrated block analysis (SCBD) framework. Analysis continued using the one-way analysis of variance (ANOVA) on the obtained data from the field experiment involving annual crops engaging the MS Excel program. The mean values' further comparison and separation utilized the $LSD_{0.05}$ test.

RESULTS AND DISCUSSION

The management of plants' growth and development with fertilizers demonstrates its effectiveness by providing optimal conditions for nutrient assimilation, growth stimulation, and increased resistance to stress conditions, which eventually contributes to increased crop yield. This is the main agronomic indicator of the feasibility and effectiveness of the nutritional elements of agro-technologies, including fertilizers. As stated above, the use of new leaf fertilizers with the inclusion of organic nutrients is an alternative to mineral fertilizers. The positive effect of foliar fertilization with humic and amino acids in winter wheat with a background of basic mineral fertilizer is also an outcome in past research (Lozek *et al.,* 1997; Bărdaş *et al.,* 2024).

The leaf fertilizers observed had an advantage as a regulated factor in the management of the production process. Past studies also confirmed the agronomic effect of fertilizer application—winter wheat and soybean plants responded positively to foliar leaf fertilization with fertilizers based on the complex of trace elements with amino acids and humic substances (Ocwa *et al.,* 2024).

Table 1. Characteristics of experimental soil.

Soil depth (cm)	Humus content (%)	pH	Plant available N (mg/kg)	P_2O_5 (mg/kg)	K_2O (mg/kg)	Content of soil fractions < 0.01 mm (%)
0-20	0.79	8.54	27.4	14.0	236.0	33.12
20-40	0.73	8.49	26.3	7.2	168.0	41.78

Table 2. Effect of leaf fertilizers on winter wheat grain yield.

Treatments	Yield (t/ha)		Means	Increase (t/ha)
	2023	2024		
Control - without fertilizers	3.33	3.19	3.26	-
P120 calculated dose - background	4.31	3.82	4.07	0.81
P120 + Amino turbo - III e/o and IV-V e/o	3.92	3.56	3.74	0.48
P120 + Ruter AA - III e/o and IV-V e/o	4.69	4.59	4.64	1.38
P120 + Geogumat - III e/o and IV-V e/o	4.18	4.57	4.38	1.12
$SSD_{0,05}$ (t/ha)	0.43	0.49		
Experience accuracy (%)	0.33	0.36		

Studies on low-fertility lightly irrigated sierozems in 2023–2024 have established that two-fold foliar fertilization in winter wheat with the studied fertilizers against the background of pre-sowing application of the calculated dose of phosphorus fertilizer significantly affected the grain yield.

The leaf fertilizers provided reliable yield increase compared with the control (0.81–1.38 t/ha) (Table 2). The greatest efficiency was evident in the foliar fertilization of winter wheat with leaf Ruter AA, along with humic acids, chelate complexes of trace elements, and amino acids of plant origin. The average yield for two years was 4.64 t/ha, which was 1.38 t and 42.3% higher than the control variant with a weak agricultural background. However, on the background with a calculated dose of phosphorus fertilizer, the grain yield increased by 0.81 t/ha. It was 0.26 t/ha less than the variant using Ruter AA, as obtained with the use of leaf fertilizer Geogumat.

Amino acid complex (Amino Turbo) as foliar fertilizer had the least effect even in comparison with phosphorus fertilizer. However, when compared with the control, it provided an increase in grain yield of up to 0.48 t/ha. The best technique for increasing the grain yield of winter wheat was the double foliar fertilization of the crop with Ruter AA fertilizer. For the rational use of fertilizers containing humic and amino acids, the data on soil availability of mobile forms of phosphorus and potassium were of primary importance, according to which applying the calculated rates of fertilizers and developing a high agro-technical background were factors (Sanina and Glukhovtsev*,* 2017; Tanirbergenov *et al.,* 2016). However, the placement of crops on soils with low availability of mobile phosphorus leads to low yield (Sychev and Shafran*,* 2013).

The presented research also proved that on light gray soils with low phosphorus content in the soil, the yield shortfall of winter wheat grain ranges from 0.81 to 1.38 t/ha. Foliar fertilization with fertilizers containing humic and amino acids had a positive effect on the soybean grain yield during 2023–2024, and the double foliar feeding with leaf fertilizer Geogumat positively affected grain yield which amounted to 4.13 t/ha (Table 3).

Application of fertilizer Ruter AA showed the effect on winter wheat and soybean grain shortage in comparison with the variant Geogumat (0.12 t/ha); however, the

Table 3 Effect of leaf fertilizers on soybean grain yield.

Treatments	Yield (t/ha)		Means	Increase (t/ha)
	2023	2024		
Control - without fertilizers	3.28	2.86	3.07	-
P94 calculated dose - background	3.94	3.57	3.76	0.69
P94 + Amino turbo - III e/o and IV-V e/o	4.35	3.40	3.88	0.81
P94 + Ruter AA - III e/o and IV-V e/o	4.42	3.60	4.01	0.94
P94 + Geogumat - III e/o and IV-V e/o	4.42	3.83	4.13	1.06
$SSD_{0,05}$ (t/ha)	0.61	0.47		
Experience accuracy (%)	4.70	4.40		

Table 4. Dynamics of mobile phosphorus averages for 2023–2024 under winter wheat and soybean crops (mg/kg of soil).

Treatments	Winter wheat (P120)			Soybean (P94)		
	1 treatment	2 treatments	harvesting	1 treatment	2 treatments	harvesting
Control - without fertilizers	39.8±2.7	44.0±5.9	36.0±1.4	25.8±3.8	25.2±6.6	18.0±4.7
P calculated dose (background)	40.5±2.5	46.0±4.7	43.7±3.8	36.8±5.7	36.5±4.5	14.7±3.0
P + Amino turbo	39.3±2.9	47.3±3.0	33.0±1.7	37.0±2.3	42.7±4.3	22.0±3.1
P + Ruter AA	37.2±1.4	41.3±2.4	38.8±3.3	30.3±1.5	45.3±3.4	37.3±1.7
P + Geogumat	41.0±3.3	48.7±2.2	36.0±3.6	36.2±1.9	35.7±2.6	30.7±3.8
Means	39.6±1.4	45.5±2.9	37.5±4.0	33.2±5.0	37.1±7.8	24.5±9.3

grain yield was higher than the control (0.94 t/ha). On soybean crops, the fertilizer with amino acids revealed an effect higher than both the control and the variant with the calculated rate of phosphorus fertilizers (3.88 t/ha). The year 2024 was distinct in increased background temperature during the growing season; the effectiveness of leaf fertilizers was lower than in 2023; nevertheless, except for biostimulant, all the fertilizers provided a desirable effect, and the grain yield was higher than the control and background RK. The effectiveness of leaf fertilizers on soybean crops significantly increased with the rise in the level of soil availability of mobile phosphorus due to the autumn application of ammophos, which was consistent with previous data (Nesterenko and Lapushkin*,* 2019).

In general, the two years' yield data showed urea and organo-mineral fertilizers as leaf fertilizers can be an alternative technique in plant nutrition management provided an increase in the content of mobile phosphorus in the soil occurs. Amino acid biostimulant in winter wheat crops was less effective in contrast to winter wheat, probably recommending its application as an anti-stress after pesticide treatments. It was evident above that against the background of the main application of phosphorus fertilizers, the efficiency of foliar treatments had a significant rise. The physiological importance of phosphorus was determined by the fact that it provides energy metabolism and activates the activity of enzymes regulating carbohydrate metabolism and protein synthesis. Moreover, it plays a pivotal role in forming the root system, which is crucial in the early stages of plant growth (Khan *et al.,* 2023).

During the field experiments, determining the dynamics of mobile phosphorus in soil in winter wheat and soybean crops emerged after foliar treatments and after harvesting. On average in the experiment during the growing season, the content of mobile phosphorus in the soil was higher under winter wheat crop (39.56, 45.46, and 37.5 mg/kg and 33.22, 37.08, and 24.54 mg/kg, respectively) (Table 4). Heterogeneity of plots in phosphorus content is also noticeable. In some variants, the variation ranges from 3.8 to 6.6 mg/kg.

The content of mobile phosphorus decreases toward the end of vegetation due to its consumption for crop yield formation. Maximum values are notable in the period after the second treatment of plants by leaf. During this period, a maximum development of the root system appeared, through which a release of organic acids and enzymes that enhanced the solubility of phosphorus compounds occurred before transferring to the available form (Baker *et al.,* 2015; Ramazanova *et al.,* 2024). In addition, during this period, an active mineralization of organic matter emerged, including at the expense of the soil microbiome, which also leads to the release of hard-to-access phosphorus compounds (Menezes-Blackburn *et al.,* 2017*)*.

Expectedly, an increased phosphorus background reached formation by the application of calculated doses of phosphorus fertilizers—from 40.5 mg/kg after the first sampling term to 48.7 mg/kg of soil by harvesting. The use of leaf fertilizers, due to the indirect influence on the nutritional regime of the soil in the relationship with the above processes, contributes to its optimization and provides the mobile phosphorus at the optimal level for winter wheat (20–40 mg/kg). However, the best indicators were remarkable in the variants where Ruter AA and Geogumat applications succeeded.

The content of mobile phosphorus in the soil under the soybean crop until the ripening phase was at the optimal level and even higher (25 mg/kg of soil minimum values and 45 mg/kg of soil maximum values). However, after harvesting, this indicator decreases almost 1.2–2.5 times. Application of leaf fertilizers on the background of P94 allows maintaining the optimal values of mobile phosphorus content (30.7–37.3 mg/kg), except for the biostimulant Amino Turbo.

By cultivating soybean in the background with low phosphorus content, it was impossible to predict stable high yields of the subsequent crop in the crop rotation because in this case, the indicators of effective soil fertility had reductions, and the soil lacked nutritional elements. The studied types of fertilizers can provide additional yields most likely due to their biostimulant potential, being a kind of corrector of mineral nutrition and mediating influence on the productive processes of plants, as well as on the nutritional regime of the soil.

CONCLUSIONS

Foliar fertilization with humic and amino acid fertilizers, supported by phosphorus, positively affected the grain yield of winter wheat (*Triticum aestivum* L.) and soybean (*Glycine max* L.), particularly with Ruter AA in winter wheat (yielding 4.0–4.6 t/ha) and Geogumat in soybean (adding 0.81–1.06 t/ha). These treatments improved the nutrient balance, achieving 68%–84% and 92%–98% yield potential in winter wheat and soybean, respectively. By enhancing soil mineralization, the foliar approach maintained optimal nutrient levels (20–40 mg/kg in wheat and 25–40 mg/kg in soybeans) and eventually enhanced crop productivity. Such protocols also reduced the agrochemical load, increasing resilience and flexibility in low-fertility soils.

ACKNOWLEDGMENT

This research received funding from the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP14870711).

REFERENCES

Arslan E, Agar G, Aydin M (2021). Humic acid as a biostimulant in improving drought tolerance in wheat: The expression patterns of drought-related genes. *Plant Mol. Biol. Rep*. 39: 508–519. https://doi.org/10.1007/s11105-020-01266-3.

Baker A, Ceasar SA, Palmer AJ, Paterson JB, Qi W, Muench SP, Baldwin SA (2015). Replace, reuse, recycle: Improving the sustainable use of phosphorus by plants. *J. Exp. Bot.* 66(12): 3523–3540.

Bărdaş M, Rusu T, Popa A, Russu F, Șimon A, Chețan F, Racz I, Popescu S, Topan C (2024). Effect of foliar fertilization on the physiological parameters, yield and quality indices of the winter wheat. *Agronomy* 14(1): 73. https://doi.org/10.3390/agronomy14010073.

Bărdaş M, Rusu T, Russu F, Șimon A, Chețan F, Ceclan OA, Rezi R, Popa A, Cărbunar MM (2023). The impact of foliar fertilization on the physiological parameters, yield, and quality indices of the soybean crop. *Agronomy* 13: 1287. doi.10.3390/agronomy13051287.

Borghi M, Fernie AR (2017). Floral metabolism of sugars and amino acids: Implications for pollinators' preferences and seed and fruit set. *Plant Physiol.* 175(4): 1510–1524. https://doi.org/10.1104/pp.17.01164.

Bhupenchandra I, Devi SH, Basumatary A, Dutta S, Singh LK, Kalita P (2020). Biostimulants: Potential and prospects in agriculture. *Int. Res. J. Pure Appl. Chem*. 21: 20–35. https://doi.org/10.9734/IRJPAC/2020/v21i1430244.

Dass A, Rajanna GA, Babu S, Lal SK, Choudhary AK, Singh R, Rathore SS, Kaur R, Dhar S, Singh T (2022). Foliar application of macro- and micronutrients improves the productivity, economic returns, and resource-use efficiency of soybean in a semiarid climate. *Sustainability* 14(10): 5825. https://doi.org/10.3390/su14105825.

Dospehov BA (2011). Metodika polevogo opyta: (s Osnovami Statisticheskoi Obrabotki Rezultatov Issledovanii). Alyans: Moskva, Russia: 352. Available online: https://search.rsl.ru/ru/record/01005422754 (accessed on May 12 2024).

Du-Jardin P (2015). Plant biostimulants: Definition, concept, main categories and regulation. *Sci. Hortic*. 196: 3–14. https://doi.org/ 10.1016/j.scienta.2015.09.02 1.

Forde BG, Lea PJ (2007). Glutamate in plants: Metabolism, regulation, and signaling. *J. Exp. Bot*. 58(9): 2339–2358. https://doi.org/10.1093/jxb/erm121.

Howe GA, Jander G (2008). Plant immunity to insect herbivores. *Annu. Rev. Plant Biol.* 59(1): 41–66.

Islam MM, Hassan MU, Ishfaq M (2024). Foliar glutamine application improves grain yield and nutritional quality of field-grown maize (*Zea mays* L.) hybrid ZD958. *J Plant Growth Regul*. 43(2): 624–637. https://doi.org/ 10.1007/s00344-023-11121-w.

Khan F, Siddique AB, Shabala S, Zhou M, Zhao C (2023). Phosphorus plays key roles in regulating plants' physiological responses to abiotic stresses. *Plants* 12: 286.

Lozek O, Fecenko J, Mazur B, Mazur K (1997). The effect of foliar application of humate on wheat grain yield and quality. *Rostl. Vyroba* 43(1): 37–41.

Meier U (2018). Growth stages of mono- and dicotyledonous plants. BBCH Monograph. Julius Kühn-Institut (JKI) Quedlinburg. Germany 204.

Menezes-Blackburn D, Giles C, Darch T, George TS, Blackwell M, Stutter M, Shand C, Lumsdon D, Cooper P, Wendler R (2017). Opportunities for mobilizing recalcitrant phosphorus from agricultural soils: A review. *Plant Soil* 427: 5–16.

Negrea A, Rezi R, Urda C, Pacurar L, Teodor R (2022) Soybean yield and quality response to foliar fertilization. *AgroLife Sci. J.* 11(1). 139–144.

Nesterenko VA, Lapushkin VM (2019). Formation of yield and grain quality of spring wheat variety Lyubava depending on the doses of nitrogen fertilizers and soil availability of mobile phosphorus. In the collection: Soil Fertility of Russia: Status and Opportunities. V.G. Sychev (ed.). Moscow. pp. 233–238.

Ocwa A, Mohammed S, Mousavi SMN (2024). Maize grain yield and quality improvement through biostimulant application: A systematic review. *J. Soil Sci. Plant Nutr.* 24: 1609–1649. https://doi.org/10.1007/s42729-024-01687-z.

Ramazanova R, Sharypova T, Zhumagulova M, Suleimenova A, Poshanov M, Ayan A, Zargar M (2024). Impact of foliar organic-mineral fertilizers on sugar beet biomass and yield in response to phosphorus and potassium levels. *Res. Crops* 25 (4): 707–716. https://doi.org/10.31830/2348-7542.2024.ROC-1139.

Sanina NV, Glukhovtsev VV (2017). Features of the use of new generation fertilizers in technologies of spring barley cultivation in arid conditions of the Middle Volga region. *Russ. Agric*. *Sci.* 3: 3–6.

Shafran SA (2020). Payback of costs for the use of nitrogen fertilizers in winter wheat top dressing. *Agrochemistry* 2: 20–27.

Shapoval OA, Mozharova IP, Ponomareva AS (2018). Efficiency of polyfunctional fertilizers with the inclusion of amino acids on cereal crops. *Plodorodie* 5: 26–29. https://doi.org/ 10.25680/S19948603.2018.104.08.

Sychev VG, Shafran SA (2013). Agrochemical Properties of Soils and Efficiency of Fertilizer Application. Moscow, VNIA. 296.

Tanirbergenov SI, Suleimenov BU, Saparov AS, Soltanayeva AM, Kabylbekova BZh (2016). The fertilizer system increasing the salt tolerance and productivity of cotton in the conditions of saline soils in Southern Kazakhstan. *Res. J. Pharm. Biol. Chem. Sci.* 7(6): 147–155.

Trevisan S, Francioso O, Quaggiotti S, Nardi S (2010). Humic substances biological activity at the plant-soil interface: From environmental aspects to molecular factors. *Plant Signal. Behav.* 5(6): 635–643. https://doi.org/10.4161/psb.5.6.11211.

Van-Oosten MJ, Pepe O, De Pascale S, Silletti S, Maggio A (2017). The role of biostimulants and bioeffectors as alleviators of abiotic stress in crop plants. *Chem. Biol. Technol. Agric*. 4: 5. https://doi.org/10.1186/ s40538–017–0089–5.

Wilczewski E, Szczepanek M, Wenda-Piesik A (2018). Response of sugar beet to humic substances and foliar fertilization with potassium. *J. Cent. Eur. Agric.* 19(1): 153–165. https://doi.org/10.5513/JCEA01/19.1.2033.

Yagodin BA, Smirnov PM, Peterburgsky AV (1989). Agrochemistry. Moscow, Agroprom publishing house, 2nd Ed., Revision and supplement. USSR. 335.

Yang Z (2005). Homoserine and asparagine are host signals that trigger in plant an expression of a pathogenesis gene in Nectria haematococca. *Proc. Natl. Acad. Sci. USA* 102(11): 4197–4202.