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THE EFFECT OF SUPERABSORBENT AND DIFFERENT RATES OF THE LOCAL FERTILIZER ON GARLIC PRODUCTIVITY IN THE FOREST-STEPPE OF UKRAINE

Viacheslav Yatsenko, Serhii Poltoretskyi, Ivan Mostoviak, Nataliia Vorobiova, Oleh Lazariev, Vitalii Kravchenko

Uman National University of Horticulture, Instytutska 1, 20301, Uman, Ukraine

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Vastutavautor:
Corresponding author: Viacheslav Yatsenko

E-mail: slaviksklavin16@gmail.com

ORCID:
0000-0003-2989-0564 (VY)
0000-0003-3334-0880 (SP)
0000-0003-4585-3480 (IM)
0000-0003-3752-314X (NV)
0000-0003-0557-3919 (OL)
0000-0003-4873-5367 (VK)

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ABSTRACT. This study aimed to determine the effect of different rates of topical fertilizers on the background of superabsorbent polymers (absorbents; SAP) on plant growth, pigments content in leaves and activity of antioxidant enzymes in leaves and soil, yield and nutritional value of products. For this purpose, an absorbent at the rate of 15 kg ha^{-1} and fertilizers were applied, spread on the soil surface 100% (control), and locally in the furrows when planting at the rate of 25, 50, 75, and 100% of the recommended rate were applied. The results showed that the use of superabsorbent polymers (SAP) and the local application of fertilizers with increasing their rate, a significant increase in chlorophyll b and the number of chlorophylls. However, the use of SAP reduced the activity of antioxidant enzymes in the leaf (superoxide dismutase by 9.5–23.2%; glutathione S-transferase by 7.4–13.4%; peroxidase by 8.4–19.0%). The bulb's weight with the absorbent increased by 31.2–45.4% compared to similar options without the introduction of absorbent. The local fertilizer without absorbent increased garlic yield by 3.5–13.9% relative to control. With the introduction of the absorbent, the local application of fertilizers contributed to the increase of yield by 4.2–25.4%. The application of fertilizers at the rate of 50 and 75% separately and together with the absorbent contributed to the improvement of nutritional value (dry matter, ash, proteins and carbohydrates, fat and caloric content of products). In conclusion, the combination of SAP with local fertilization in crop production technology can be used in today's dynamic climate conditions, due to their beneficial effects on plant productivity and savings and efficient use of water and fertilizers. Further research consists of a more detailed study of the rate of application of absorbents, the duration of their effective action, and the rate and ratio of nutrients.

Introduction

Worldwide, drought stress is one of the most important factors reducing crop production (Beigi *et al.*, 2020). The presence of water in the soil is one of the most important factors in increasing crop yields. Therefore, the priority is to increase the efficiency and optimal use of water resources as one of the main axes of stable agriculture in unstable conditions of moisture. Accordingly, one way to increase the soil water supply is to use a superabsorbent polymer that provides water for plants (Dehkordi *et al.*, 2018).

Superabsorbent polymers (SAP) can also be identified as absorbent polymers, absorbent gels, aqueous gels, or hydrogels. They are synthetic high molecular materials that can hyperaccumulate water up to 100% of its weight (insert reference). In addition, SAPs are mainly used to improve soil properties and they usually consist of sugar-like hygroscopic materials that turn into a transparent gel when added to the water (Hüttermann *et al.*, 2009).

Superabsorbents, depending on their source and structure, are divided into two main groups: natural and synthetic. Synthetic superabsorbent polymers, depending on the type of use of monomer in their synthesis, usually are divided into three groups: 1 – cross-linked polyacrylates and lyacrylamides; 2 – hydrolyzed cellulose-polyacrylonitrile (PAN) or starch PAN graft copolymers; 3 – cross-linked copolymers of maleic anhydride. The SAPs used in agriculture are polyelectrolyte gels often composed of acrylamide (AM), acrylic acid (AA), and potassium acrylate (Zohuriaan-Mehr, Kabiri, 2008). They are used in gardens, landscapes, and agriculture to protect and preserve soil moisture and slow the release of water through the soil (Orzeszyna *et al.*, 2006; Thombare *et al.*, 2018). Superabsorbent polymers promote better growth and higher yields by increasing the water storage capacity in the soil (El-Hady *et al.*, 2006; Sarvas *et al.*, 2007), reducing the consumption of the water and soil nutrients (Adams, Lockaby, 1987), reducing the water evaporation from the soil surface (Sivapalan, 2001) and increasing the soil aeration (Orzeszyna, 2006). These materials increase the interval between watering which saves water and energy.

The use of absorbent polymers, especially the superabsorbent ones, has several benefits such as conservation of the water, lowering the surface of runoff, avoiding soil erosion, and improving the performance of different soil fertilizers (Scott, Blair, 1988; Xi, Zhang, 2021).

The yield of garlic is quite low and is 10–14 t ha^{-1} (in Ukraine), which is 30–50% of the theoretically possible. This leads to the need for the development and improvement of the elements of cultivation technology for each soil-climatic zone to significantly increase the yields. It is impossible to achieve this without the use of mineral fertilizers (Bondarchuk, 2008; Chaithra, Sridhara, 2018; Mao *et al.*, 2021). In addition, the use of fertilizers significantly affects biochemical composition, nutritional value and taste, and shelf life. Mineral fertilizers have a high cost, they should be used with the greatest efficiency and payback. One of the most rational ways to apply fertilizers that can significantly increase their efficiency and reduce their costs per unit of yield is local. Studies examining the comparative effectiveness of spreading and local fertilization methods have shown the advantage of the latter in growing different crops (Trapeznikov, Tavilskaya, 1980; Jing *et al.*, 2012).

Intensive agriculture indicates that fertilizers are the material basis for the quantity and quality of crop products and a source of nutrients for plants. It is known that with this method of application it is possible to obtain a higher return from a much lower rate of fertilizer (Kubareva, 1980; Islam *et al.*, 2011; Fernando *et al.*, 2017). The influence of the local method of fertilizer application on physiological processes is manifested not only in the early stages of plant development but also in the period of crop formation, that is this method affects the size of the crop and its quality (Kardinalovskaya, 1980; Fomenko *et al.*, 2015; Vasiliev *et al.*, 2022).

Intensive technology, unbalanced mineral nutrition, and less or no organic fertilizers lead to depletion of soil fertility (Palm *et al.*, 1997). The local use of mineral fertilizers is of great importance today for their efficient use and optimization of crop productivity (Shalini *et al.*, 2002; Belousov *et al.*, 2020).

After analyzing the above provisions, an experimental study was conducted to identify the impact of local application of mineral fertilizers in combination with the absorbent on the level of realization of the biological potential of the winter garlic cultivar 'Lubasha' which has special relevance and practical significance in the dynamic climate conditions.

Materials and Methods

Research on the technology of growing the winter garlic variety 'Lubasha' in the Right Bank Forest-Steppe of Ukraine using spreading and local methods of application and different rates of fertilizers to optimize mineral nutrition of the winter garlic plants and rational use of fertilizers, conducted in 2019–2021 Uman National University of Horticulture.

The soil was black, puddle, heavy loam with a well-developed humus horizon (about 2.9% of humus) (Krupskiy, Polupan, 2018), (Table 1), in the depth of 40–45 cm. Soil pH was determined in the water (soil to water ratio 1:1). The electrical conductivity (EC_e) of the soil suspension was measured using the conductivity of the meter. The P and K were determined by the ammonium bicarbonate-diethylenetriaminepentaacetic acid (ABDTPA) method (Ryan *et al.*, 2001).

Total N, including nitrate and nitrite, was determined by distillation after digestion of the sample with a mixture of salicylic acid and sulfuric acid plus sodium thiosulfate (Bremner, Mulvaney, 1982). Nitrate N (including nitrite-N) was extracted with 1.0 mol L^{-1} N hydrochloric acid (HCl) solution (Blacquiere *et al.*, 1987), reduced with zinc powder (Broaddus *et al.*, 1965) and then determined using the Griess-Ilosvay nitrite method (Keeney, Nelson 1982).

The organic matter contents of compost and soil were determined by the loss of weight at 450 °C (Gagnon *et al.*, 1997).

Table 1. Physical and chemical parameters of the soil of the experimental field (X ± SD)

Indicator	Actual content before fertilizer application		
	2018/19	2019/20	2020/21
Organic carbon%	1.48 ± 0.11	1.40 ± 0.08	1.43 ± 0.10
Acidity (pH)	6.0 ± 0.09	6.2 ± 0.13	6.2 ± 0.12
EC , µS cm^{-}	24.6 ± 0.48	25.1 ± 0.50	26.2 ± 0.54
Extractable P (ABDTPA), mg kg^{-1}	4.2 ± 0.10	5.5 ± 0.12	4.7 ± 0.12
Extractable K (ABDTPA), mg kg^{-1}	4.9 ± 0.12	6.3 ± 0.15	5.9 ± 0.15
NO_3N, mg kg^{-1}	3.5 ± 0.06	4.2 ± 0.08	4.4 ± 0.11

The establishment of experiments was performed by randomized design. Repetition of the experiment – four times. The accounting area one variant of the research land is 100 m^2. Garlic planting was carried out on October, 10–15 according to the 45×6 cm scheme. The scheme of the experiment included the method of cultivation (factor A – without absorbent (control) and with absorbent at the rate of 25 kg ha^{-1}) and mineral rates (25, 50, 75 and 100% of the recommended rate) of fertilizers (urea (46% nitrogen content), double superphosphate (50% phosphorus content) and potassium sulfate (50% potassium content) with spreading and local application in rows before planting. The option with 100% by the application of fertilizers is taken as a control (Table 2).

Table 2. The lack of nutrients for the formation of the planned harvest and the rate of application of mineral fertilizers (X ± SD)

Variant	Fertilizer need, kg ha^{-1}	Fertilizers, kg ha^{-1} were applied		
		2019	2020	2021
Control*	$N_{240}P_{120}K_{120}$ (spreading 100%)	$N_{236,5}P_{115,8}K_{115,1}$	$N_{235,8}P_{114,5}K_{113,7}$	$N_{235,6}P_{115,3}K_{114.1}$
100%	$N_{240}P_{120}K_{120}$ (locally)	$N_{236,5}P_{115,8}K_{115,1}$	$N_{235,8}P_{114,5}K_{113,7}$	$N_{235,6}P_{115,3}K_{114.1}$
75%	$N_{180}P_{90}K_{90}$ (locally)	$N_{176,5}P_{85,8}K_{85,1}$	$N_{175,8}P_{84,5}K_{83,7}$	$N_{175,6}P_{85.3}K_{84,1}$
50%	$N_{120}P_{60}K_{60}$ (locally)	$N_{116,5}P_{55,8}K_{55,1}$	$N_{115,8}P_{54,5}K_{53,7}$	$N_{115.6}P_{55.3}K_{54.1}$
25%	$N_{60}P_{30}K_{30}$ (locally)	$N_{56,5}P_{25,8}K_{28,8}$	$N_{55,8}P_{24,5}K_{23,7}$	$N_{55.6}P_{25.3}K_{24.1}$

* – control (100% of the recommended rate of NPK scatter)

Analysis of the above data on air temperature and precipitation from October 2018 to September 2020, compared to average long-term data (for 30 years – from 1961 to 1990), indicates a characteristic feature of this agricultural year was increased temperature background, an insufficient amount of precipitation in summer and autumn. The average air temperature of the agricultural year during the growing season of garlic plants was significantly higher in 2019 (May–June) was 17 and 23.4 °C, which was 1.6 and 4.4 °C higher than the long-term average (Fig. 1).

The total amount of precipitation during the growing season of garlic plants significantly exceeded the average long-term mark in May 2020 and June, July, and August 2021, which reduced the variation in growth and productivity in 2021. The long-term summer deficit of precipitation was noted in 2019 and 2020 which was a limiting factor for the growth and development of garlic (Fig. 2).

MaxiMarin granules: 1 kg of absorbent can accumulate up to 400 litres of water. The information provided by the manufacturer prevents soil compaction, it is safe, neutral, non-toxic, and inert to pesticides. The term of efficiency of the absorbent in the soil is up to 10 years. Because it is based on potassium, it decomposes into nitrogenous compounds, carbon dioxide, and water after decomposition.

Characteristics of the absorbent:

Basis: crosslinked copolymer of polyacrylamide and potassium polyacrylate.

Form: white granules.

Particles size: from 70 to 2000 microns.

Density: 0.5–0.6 g $cm^{3\ -1}$.

pH: 6.0–6.8.

Moisture content: 5% (± 2%)

The powder (granules) of the absorbent before the application was thoroughly mixed with fertilizers. The local application of absorbent and mineral fertilizers was applied before planting by a cultivator with fertilizer spreaders to a depth of 20–25 cm.

The scheme of the experiment was based on the results of chemical analysis of the soil that the content of nutrients was brought to the optimum level.

Biometric research. The leaf length and width, leaf blade area, and total leaf area per plant on the BBCH 53 were determined; the number of leaves per plant was calculated, and the leaf blade area was determined by a calculated (linear) method (Nichiporovich, 1969), using the parameters of length and width of the leaf by the formula:

$$Sn = 0.74 \times ab, \quad (1)$$

where:

Sn – single leaf area, cm²;

a – the largest leaf width, cm;

b – leaf length, cm;

0.74 is the leaf configuration coefficient.

Leaf index is the ratio of the total leaf area of plants to the area of soil on which they are located and was determined by the formula (Nichiporovich, 1969):

$$LAI = \frac{S_{total}}{0.1\ ha^{-1}}, \quad (2)$$

where

LAI – the leaf index;

S_{total} – total leaf area (thousand m^2 ha^{-1}).

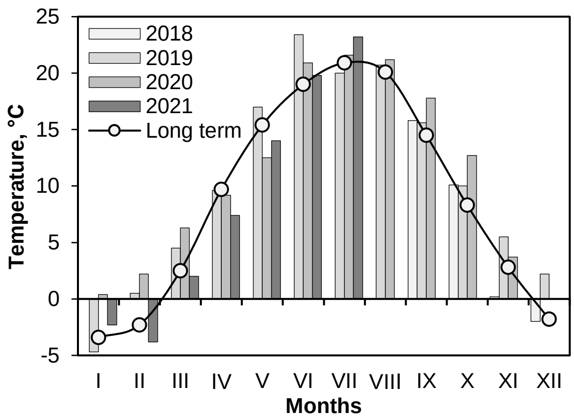


Figure 1. The average air temperature, °C (2019–2021)

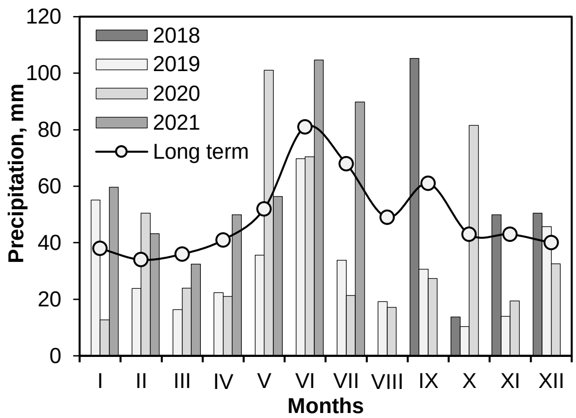


Figure 2. The amount of precipitation, mm (2019–2021)

We studied the effect of superabsorbent and local application of fertilizers on the garlic plant (enzymes activity, the productivity of plants, pigments contents in leaf; protein, fats, carbohydrate, and ash in cloves and enzymatic activity of soil). All analyzes were performed in four replicates.

Plant material. Garlic (*Allium sativum* L.) cv. 'Lubasha'.

Determination of chlorophylls

The plant material was washed with distilled water and air-dried in a shady, well-ventilated room at the temperature of 22–25°C. Then, 0.10–0.05 g of the sample was weighed and triturated with 5 mL of the solvent (ethanol) for 15 min. The obtained suspension was filtered into a volumetric flask (capacity of 10 mL) and supplemented with ethanol. Concentrations (µg mL^{-1}) of chlorophylls *a* and *b*, were determined using equations published by Lichtenthaler and Buschmann (2001):

$$\text{Chlorophyll } a = 13.36A_{664.1} - 5.19A_{648.6} \quad (3)$$

$$\text{Chlorophyll } b = 27.43\mathrm{A}_{648.6} - 8.12\mathrm{A}_{664.1} \quad (4)$$

The activity measurements of antioxidant enzymes. Enzyme activities were determined: A 1 g of plant tissue from control and treated plants was homogenized on ice in 4 ml extraction buffer (50 mM^{-1} phosphate buffer pH 7.0, containing 1 mM EDTA, 1 mM phenylmethylsulfonyl fluoride, and 1% polyvinylpolypyrrolidone). The homogenate was centrifuged for 25 min at 15 000 and 4 °C. The supernatant was used for enzyme activity assays. The means ± SD were calculated from the data of at least three independent measurements. SOD (superoxide dismutase) activity was determined spectrophotometrically by measuring the ability of the enzyme to inhibit the photochemical reduction of nitro blue tetrazolium (NBT) in the presence of riboflavin in light (Dhindsa *et al.*, 1981). One unit (U^{-1}) of SOD was the amount that causes 50% inhibition of NBT reduction in light. The enzyme activity was expressed in terms of specific activity (U mg $protein^{-1}$). POD (peroxidase) activity was determined by monitoring the increase in absorbance at 470 nm during the oxidation of guaiacol (Upadhyaya *et al.*, 1985). The amount of enzyme-producing 1 µmol min^{-1} of oxidized guaiacol was defined as 1 U-1. GST (glutathione S-transferase) activity was determined spectrophotometrically by using an artificial substrate, 1-chloro-2.4-dinitrobenzene (CDNB), according to Habig *et al.* (1974). One U is the amount of enzyme-producing 1 µmol conjugated product in 1 min, ε_{340}=9.6 mM cm^{-1}. The protein contents of the extracts were determined by the method of Bradford (1976).

The enzymatic activity of soil. Samples for soil enzymatic activity testing were collected from 20 random locations, from the topsoil (0–25 cm) from each fertilization variant, once after the crop was harvested. Tests covered the activity of dehydrogenases, urease, and protease. The enzyme activity was determined by the following methods: the activity of dehydrogenases was expressed in cm^3 H_2, required to reduce triphenyltetrazole chloride (TTC) to TFP (triphenyl formazan) (Thalmann *et al.*, 1968); urease, in mg N-NH4+, obtainned from hydrolyzed urea (Ladd, Butler, 1972); proteases, in mg of tyrosine developed from sodium caseinate (Von Mersi *et al.*, 1991; Wolinska *et al.*, 2010). The activity of tested enzymes was analyzed in soil with natural humidity, and the results were converted into absolutely dry soil mass. Dehydrogenases, by the Thalmann method, using a 1% solution of TTC as a substrate and 96-h incubation at 37 ºC, expressing their activity in cm^3 H_2 kg^{-1} d^{-1} (for 1 kg of soil in 24 h). Urease (AU), by the method of Zantu (Zantua, 1976), using a 2.5% urea solution as a substrate and an 18-h incubation at 37 ºC, expressing the enzyme activity in mg $N\text{-}NH_4$ + kg^{-1} h^{-1} $N\text{-}NH_4$ + (for 1 kg of soil in 1 h). Proteases (AP), by the method of Ladd and Butler (1972), using a 1% solution of sodium caseinate as a substrate and using a 1 h incubation at 50 ºC, expressing the enzyme activity in mg of tyrosine kg h^{-1} (per 1 kg of soil in 1 h).

The bulb dry matter (%). The average dry matter weight (g) of bulbs after curing was measured by drying 10 randomly sampled bulbs in an oven with a forced hot air circulation at 70 °C until a constant weight was obtained. The percentage of bulb dry matter was calculated by taking the ratio of the dry weight to the fresh weight of the sampled bulbs and multiplying it by 100.

The nutritional value. Proteins, fats, carbohydrates and ash content were determined by using standard methods described in the procedures of the American Organization of Analytical Chemists (International Organization of International, AOAC International) (Horwitz, Latimer, 2005). The crude fat was determined using a Soxhlet apparatus (Behr R 106 S, Germany) with petroleum ether, according to the AOAC 920.85 methodology (Horwitz, Latimer, 2016). The content of ash was determined by burning at 600 °C to constant mass following procedures AOAS 923.03 (Horwitz, Latimer, 2016). The energy was calculated by the formula:

$$Energy, kcal = 4 \times (protein) + 4 \times (carbohydrate) + 9 \times (fat) \quad (5)$$

Statistical analysis

Statistical processing of the obtained results was performed with the calculation of the arithmetic mean (x) standard deviation (SD), calculated using Microsoft Excel 2016 and Statistica 10. The obtained data were compared using an analysis of variance. The validity of the research and the significance of the differences between the mean values of the variables examined were evaluated by the dispersion and correlation analysis.

Results

The formation and proper functioning of the leaf apparatus is a determining factor in the productivity of the plant and its crops. The chlorophyll content increased with increasing the concentration of fertilizers. The content of chlorophyll a decreased with the introduction of SAP, while the content of chlorophyll b and total chlorophyll increased. The highest content of chlorophyll b (0.78% d.w.$^{-1}$) and total chlorophyll (2.01% d.w.$^{-1}$) was obtained in plants grown using absorbent and local application of 100% fertilizer (Table 3).

Table 3. Pigment and leaf complex of garlic plants of the winter cultivar 'Lubasha' depending on absorbent and fertilizer (2019–2021) (X ± SD)

Growing method (factor A)	Fertilizer rate,% of recommended (factor B)	Chlorophyll content in the leaves,% d.w.$^{-1}$ Chl. a	Chl. b	∑ Chl. a+b	No. of leaves, pcs plant^{-1}	Leaf area, cm^2	Leaf index
Without absorbent	Control (100% NPK spreading)*	1.26 ± 0.032	0.57 ± 0.015	1.83 ± 0.225	8.1 ± 0.7	60.6 ± 3.2	1.09 ± 0,04
	25% NPK locally	0.98 ± 0.027	0.47 ± 0.010	1.45 ± 0.147	7.7 ± 1.1	53.3 ± 0.4	0.92 ± 0,13
	50% NPK locally	1.21 ± 0.005	0.57 ± 0.007	1.77 ± 0.200	7.7 ± 1.1	57.2 ± 1.4	0.98 ± 0,11
	75% NPK locally	1.32 ± 0.036	0.58 ± 0.019	1.90 ± 0.200	8.2 ± 1.1	60.8 ± 1.0	1.11 ± 0,13
	100% NPK locally	1.34 ± 0.012	0.61 ± 0.019	1.94 ± 0.155	8.4 ± 0.8	63.8 ± 0.8	1.19 ± 0,13
Application of absorbent 25 kg ha^{-1}	Control (100% NPK spreading)*	1.21 ± 0.025	0.70 ± 0.011	1.91 ± 0.079	8.4 ± 0.5	74.4 ± 3.3	1.39 ± 0,02
	25% NPK locally	0.91 ± 0.020	0.62 ± 0.011	1.53 ± 0.045	8.5 ± 0.5	67.1 ± 2.4	1.26 ± 0,03
	50% NPK locally	1.11 ± 0.012	0.73 ± 0.017	1.84 ± 0.034	8.8 ± 0.4	71.8 ± 2.8	1.40 ± 0,01
	75% NPK locally	1.14 ± 0.014	0.77 ± 0.016	1.91 ± 0.032	9.0 ± 0.6	75.6 ± 3.3	1.51 ± 0,03
	100% NPK locally	1.17 ± 0.013	0.84 ± 0.023	2.01 ± 0.050	9.3 ± 0.6	80.1 ± 2.9	1.65 ± 0,04
$LSD_{0.05}$	A	0.029	0.017	0.010	0.10	0.88	0,02
	B	0.046	0.027	0.016	0.15	1.39	0,02
	A×B	0.065	0.038	0.023	0.22	1.96	0,03
Years	2019	1.21 ± 0.152	0.51 ± 0.108	1.72 ± 0.158	7.8 ± 0.64	65.2 ± 10.77	1.15 ± 0.28
	2020	1.17 ± 0.142	0.59 ± 0.112	1.89 ± 0.179	8.8 ± 0.43	63.1 ± 8.77	1.24 ± 0.23
	2021	1.15 ± 0.115	0.64 ± 0.119	2.00 ± 0.183	8.3 ± 0.51	64.1 ± 9.74	1.20 ± 0.25
	$LSD_{0.05}$	0.047	0.023	0.075	0.41	2.56	0.059

* – control (100% of the recommended rate of NPK scatter)

The indicator "number of leaves, pcs plant^{-1}" with the introduction of the absorbent increased on average, compared to the options without absorbent by 0.7–1.1 ($LSD_{0.05}$ – 0.22). The local application of fertilizers at the rate of 25 and 50% of the recommended contributed to an increase in the number of leaves against control by 0.1 pcs plant^{-1}. With the application of 75 and 100% of fertilizers locally, this figure increased by 0.6 and 0.8 pieces. (8.6 and 10.5%). When using an absorbent with local application of fertilizers, garlic plants increased the number of leaves by 0.2; 0.5; 0.8 and 1.1 pcs plant^{-1}. (+2.4...+12.7% relative to control).

The indicator of leaf area increased with the use of absorbent by 14.8–26.1% compared to similar options without absorbent. The local application of fertilizers without absorbent contributed to the increase of this indicator by 8.9–30.4%, with the introduction of absorbent the difference increased to 19.6–42.7%. The use of absorbents contributed to an increase in the leaf area of plants by 24.4–42.5% compared to similar options without absorbents. Moreover, the difference was the most significant for the application of 50% of fertilizers locally. The increase in the number of leaves and their area in total contributed to the formation of the leaf area of the plant and the leaf index greater than the control without the introduction of absorbent by 11.0–44.1%; for the use of absorbent by 22.4–60.8, which significantly affected the performance indicators, (Table 3). Our results are similar to those obtained by Ulianych *et al.* (2020) using absorbents in the cultivation of spinach, Havrilyuk *et al.* (2021) with basil.

Besides the direct effect of SAP application on plant growth and development, the increases in amino acid contents of plants make them more tolerant to the stress conditions during the vegetation period, as an indirect positive effect of SAP. The present results show that the SAP application does not cause any oxidative stress in plants. On the contrary, it reduces the formation of free oxygen radicals causing cellular damage.

Plants that were under stress with water deficiency showed a significant increase in the activity of SOD, GST and POD in the leaf compared to the versions without absorbent. The use of superabsorbents reduced the activity of antioxidant enzymes (SOD by 9.5–23.2%; GST by 7.4–13.4%; POD by 8.4–19.0%), (Table 4).

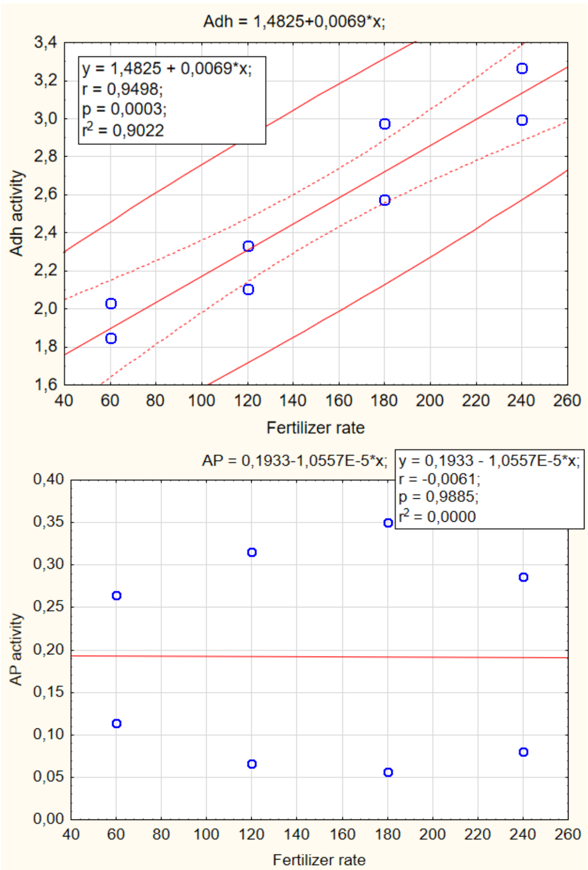
The regression analysis shown in Figure 2 showed a close dependence of dehydrogenase activity on the level of nitrogen fertilization (R^2 = 0.90); the weak relationship between urease activity and nitrogen level (R^2 = 0.37) and did not show the dependence of protease activity on the level of nitrogen fertilizer application.

The activity of soil enzymes reflects the general range of the oxidative activity of soil microflora, and therefore is used as an indicator of microbial activity (Perucci, 1992; Masciandaro *et al.*, 1994). The results of the research indicate obvious changes in the enzymatic activity of the soil under the influence of absorbent and differentiated fertilizer. In the variants fertilized locally in the norm of 50% or more, the activity of the analyzed enzymes was significantly higher than in the control variant (100% of the spreading norm). The activity of enzymes during the growing season depended mainly on the individual characteristics of the studied enzyme. The impact of years of research on enzymatic activity was high, especially in 2021, due to the different responses of enzymes to atmospheric conditions during the years of study. The data show that the absorbent significantly reduced the activity of enzymes.

Table 4. The activity of enzymes in the leaves and rhizosphere of garlic depends on the absorbent and fertilizer (2019–2021) (X ± SD)

Growing method (factor A)	Fertilizer rate,% of recommended (factor B)	Enzyme activity					
		In the leaves			In the rhizosphere		
		SOD, U mg^{-1} protein	GST, U mg^{-1} protein	POD, U mg^{-1} protein	Adh, cm^3 H_2 kg^{-1} d^{-1}	AU, mg NH_4NO_3 + kg^{-1} h^{-1}	AP, mg tyrosine kg^{-1} h^{-1}
Without absorbent	Control (100% NPK spreading)*	8.36 ± 1.34	21.73 ± 3.84	73.14 ± 14.45	2.19 ± 0.14	12.35 ± 0.42	15.35 ± 0.95
	25% NPK locally	8.50 ± 1.59	21.90 ± 4.12	75.53 ± 18.39	2.03 ± 0.14	10.79 ± 0.61	15.19 ± 0.50
	50% NPK locally	8.65 ± 1.61	22.53 ± 3.92	80.00 ± 18.24	2.33 ± 0.19	13.38 ± 0.49	15.90 ± 0.59
	75% NPK locally	8.82 ± 1.66	23.80 ± 4.10	86.04 ± 18.28	2.98 ± 0.15	14.33 ± 0.49	16.44 ± 0.66
	100% NPK locally	10.32 ± 0.76	26.74 ± 2.07	99.33 ± 7.92	3.27 ± 0.24	15.24 ± 0.85	17.18 ± 0.54
Application of absorbent 25 kg ha^{-1}	Control (100% NPK spreading)*	6.54 ± 0.25	18.87 ± 1.03	67.01 ± 2.50	1.97 ± 0.10	8.87 ± 0.15	14.24 ± 0.20
	25% NPK locally	6.62 ± 0.34	18.97 ± 1.86	61.20 ± 1.63	1.85 ± 0.13	8.69 ± 0.10	13.56 ± 0.21
	50% NPK locally	6.69 ± 0.36	19.60 ± 1.84	65.63 ± 2.10	2.11 ± 0.13	9.49 ± 0.09	14.62 ± 0.12
	75% NPK locally	6.77 ± 0.40	20.40 ± 1.70	69.73 ± 1.18	2.57 ± 0.10	9.93 ± 0.10	15.47 ± 0.11
	100% NPK locally	9.33 ± 0.17	24.77 ± 1.03	82.13 ± 1.72	3.00 ± 0.10	11.92 ± 0.37	15.81 ± 0.15
$LSD_{0.05}$	A	0.141	1.30	5.33	0.070	0.221	0.209
	B	0.224	2.06	8.43	0.110	0.350	0.331
	A×B	0.317	2.92	11.93	0.156	0.496	0.468
Years	2019	8,97 ± 1.66	25.03 ± 3.05	84.82 ± 16.07	2.62 ± 0.53	11.97 ± 2.62	15.84 ± 1.24
	2020	8.20 ± 1.53	21.77 ± 3.28	78.50 ± 12.92	2.38 ± 0.48	11.43 ± 2.23	15.41 ± 1.06
	2021	7.02 ± 1.27	18.99 ± 2.57	64.60 ± 12.37	2.28 ± 0.48	11.09 ± 2.11	14.88 ± 0.97
	$LSD_{0.05}$	0.40	1.09	3.79	0.12	0.45	0.76

* – control (100% of the recommended rate of NPK scatter); SOD – superoxide dismutas; GST – glutathione S-transferase; POD – peroxidase; Adh – dehydrogenases; AU – urease; AP – proteases.



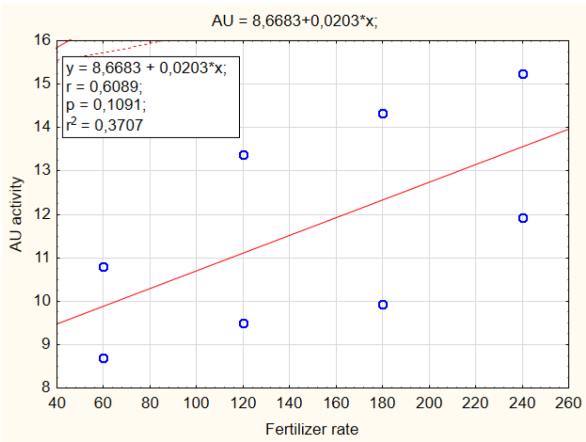


Figure 2. Spot graphs and theoretical regression line at rectilinear correlation with enzyme activity indicators and N fertilizer rate (Adh – dehydrogenases; AU – urease; AP – proteases)

The bulb weight on average with the use of absorbent increased by 8.3–21.9 g (31.2–45.4%) compared to similar options without absorbent. Local application of fertilizers without absorbent contributed to an increase in the bulb weight by 3.1–13.0 g (18.4–22.6%) relative to control, at $LSD_{0.05}$–0.90 (A), garlic plants of similar variants with the application of absorbent, increased the bulb weight by 1.2–12.3 g (2.1–21.2%) which indicates that the presence of sufficient moisture increases the efficiency of fertilizers and the level of realization of the biological potential. However, this figure in both versions of the experiment with 25% of the fertilizer rate was lower than the control by 8.1% in the version without absorbent and 6.8% with absorbent.

Garlic growing with the introduction of absorbent contributed to an increase in yield by 2.4–7.1 t ha^{-1} compared to similar options without absorbent. The local application of fertilizer without absorbent contributed to the increase in garlic yield by 0.4–1.5 t ha^{-1} (3.5–13.9%) relative to the control at the level of $LSD_{0.05}$–0.37 t ha^{-1}. With the application of the absorbent, the local application of fertilizers contributed to the increase in yield by 0.6–3.9 t ha^{-1} (4.2–25.4%) relative to the production control with 100% application of spreading fertilizers (Table 5).

Similar results of seed yield were obtained with rapeseed (Shekari *et al.*, 2015), green mass of spinach (Ulianych *et al.*, 2020) and basil (Havrilyuk *et al.*, 2021), hay (Jnanesha *et al.*, 2021).

The level of realization of biological potential was quite low. This phenomenon can be explained by the fact that in the years of research, during the rooting period, there was a fairly small amount of precipitation, especially in the 2019/20 agricultural year. At the same time, a sufficient amount of precipitation during the period of intensive growth contributed to the formation of a larger mass of bulbs, relative to 2018/19, which affected the yield, but in 2019/20 and 2020/21 increased the rate of rot by plants, which reduced yields.

Without the use of the absorbent, the yield is reduced, but the biochemical characteristics of garlic are significantly improved and the caloric content of the product is generally increased (Table 6).

Depending on the application of absorbent, the content of absolutely dry matter in garlic bulbs decreased by 2.0–4.1% compared to similar variants without absorbent. Thus, when growing garlic without absorbent, the dry matter content decreased from 30.9% in the control to 27.7% in the variant with 100% topical fertilization. With the application of absorbents, this figure decreased from 26.8% in the control to 24.3% in the version with 100% application of fertilizers locally. The maximum dry matter content was observed in the variants with the application of 25 and 50% of fertilizers.

Table 5. Bulb weight and yield of garlic depending on the absorbent and fertilizer (2019–2021) (X ± SD)

Growing method (factor A)	Fertilizer rate,% of recommended (factor B)	Mass of bulbs, g	CV, %	Yield, t ha^{-1}	CV, %
Without absorbent	Control (100% NPK spreading)*	44.6 ± 9.2	21	11.7 ± 2.4	20
	25% NPK locally	37.1 ± 7.3	20	8.8 ± 1.2	14
	50% NPK locally	46.1 ± 10.1	22	11.8 ± 2.3	19
	75% NPK locally	47.5 ± 9.9	21	12.4 ± 2.4	19
	100% NPK locally	50.0 ± 10.3	21	13.1 ± 2.6	20
Application of absorbent 25 kg ha^{-1}	Control (100% NPK spreading)*	54.8 ± 7.3	13	15.0 ± 0.8	6
	25% NPK locally	47.5 ± 5.0	10	11.9 ± 1.6	13
	50% NPK locally	56.2 ± 6.4	11	15.0 ± 0.9	6
	75% NPK locally	60.2 ± 8.1	13	15.6 ± 0.8	5
	100% NPK locally	65.2 ± 9.3	14	17.0 ± 1.0	6
$LSD_{0.05}$	A	4.11		0.83	
	B	6.50		1.31	
	A×B	9.19		1.86	
Years	2019	43.0 ± 11.87	28	11.6 ± 3.30	28
	2020	60.2 ± 9.58	16	14.5 ± 2.32	16
	2021	49.6 ± 3.76	8	13.6 ± 2.09	15
	$LSD_{0.05}$	2.54		0.66	

* – control (100% of the recommended rate of NPK scatter)

Table 6. The content indicators of the components of biochemical composition and nutritional value of garlic depending on the absorbent and fertilizer rate (X ± SD)

Growing method (factor A)	Fertilizer rate,% of recommended (factor B)	Nitrates, mg kg^{-1}	Dry matter, %	Ash, g 100 g f. $w.^{-1}$	Protein, g 100 g f. $w.^{-1}$	Carbohydrates, g 100 g f. $w.^{-1}$	Fat, g 100 g f. $w.^{-1}$	Energy, kcal 100 g f. $w.^{-1}$
Without absorbent	Control (100% NPK spreading)*	68.5 ± 2.50	30.9 ± 3.25	1.16 ± 0.02	5.84 ± 0.49	27.40 ± 0.20	0.28 ± 0.02	135.48 ± 1.02
	25% NPK locally	66.4 ± 3.10	32.8 ± 2.66	1.10 ± 0.02	5.69 ± 0.48	25.18 ± 0.18	0.24 ± 0.03	125.68 ± 0.99
	50% NPK locally	85.0 ± 4.75	30.9 ± 2.96	1.22 ± 0.03	5.90 ± 0.53	27.84 ± 0.25	0.41 ± 0.02	138.61 ± 1.29
	75% NPK locally	105.0 ± 7.75	29.3 ± 3.82	1.27 ± 0.02	6.43 ± 0.70	26.68 ± 0.19	0.45 ± 0.03	136.49 ± 1.90
	100% NPK locally	113.5 ± 6.03	27.7 ± 3.89	1.33 ± 0.04	6.61 ± 0.60	24.21 ± 0.16	0.38 ± 0.04	126.70 ± 1.46
Application of absorbent 25 kg ha^{-1}	Control (100% NPK spreading)*	61.5 ± 1.63	26.8 ± 2.12	1.21 ± 0.01	5.29 ± 0.20	28.04 ± 0.10	0.31 ± 0.03	136.11 ± 1.18
	25% NPK locally	58.9 ± 0.90	30.9 ± 2.35	1.15 ± 0.01	5.18 ± 0.19	25.80 ± 0.16	0.26 ± 0.03	126.29 ± 0.37
	50% NPK locally	78.7 ± 3.45	28.3 ± 2.20	1.30 ± 0.03	5.48 ± 0.27	28.57 ± 0.29	0.46 ± 0.03	140.37 ± 0.62
	75% NPK locally	97.7 ± 8.0	25.8 ± 2.35	1.34 ± 0.04	5.67 ± 0.21	27.23 ± 0.17	0.50 ± 0.04	136.10 ± 0.44
	100% NPK locally	103.0 ± 8.94	24.3 ± 2.35	1.38 ± 0.02	5.89 ± 0.16	25.05 ± 0.04	0.41 ± 0.03	127.45 ± 0.17
$LSD_{0.05}$	A	1.62	0.53	0.013	0.14	0.08	0.017	0.31
	B	2.57	0.85	0.021	0.22	0.13	0.027	0.49
	A×B	3.63	1.20	0.030	0.32	0.18	0.038	0.69
Years	2019	83.8 ± 19.94	31.99 ± 3.58	1.22 ± 0.09	6.16 ± 0.57	26.38 ± 1.41	0.33 ± 0.08	133.17 ± 5.46
	2020	80.5 ± 34.20	29.34 ± 3.82	1.26 ± 0.10	5.96 ± 0.59	26.61 ± 1.48	0.37 ± 0.10	133.58 ± 6.00
	2021	71.9 ± 28.99	26.69 ± 3.63	1.25 ± 0.09	5.29 ± 0.28	26.80 ± 1.49	0.41 ± 0.09	132.04 ± 5.79
	$LSD_{0.05}$	3.93	1.47	0.061	0.29	1.06	0.018	6.64

* – control (100% of the recommended rate of NPK scatter)

The use of absorbent and local application of fertilizers increased the ash content from 1.16 g 100 g f. w.$^{-1}$ in the control without absorbent up to 1.38 g 100 g f. w.$^{-1}$ with the introduction of absorbent and 100% fertilizer.

The content of nitrates and protein decreased with the use of the absorbent but increased with the local application of fertilizers. These findings may be because protein is considered a good indicator of plant resistance to water deficiency, as the water intake causes hydrolysis and catabolism of proteins, releasing free amino acids and ammonia, as well as proline (Fayed *et al.*, 2018; Mayer *et al.*, 2021). Moreover, fertilizer application rate and soil moisture have been reported to significantly affect protein content in garlic bulbs (Diriba-Shiferaw *et al.*, 2014). The local application of fertilizers contributes to a greater accumulation of nitrates in the bulbs, so it is advisable to use these products for processing. The maximum permissible concentration of nitrates is 80 mg kg^{-1}, while in our studies their content exceeded the permissible level at 50% of fertilizers application locally without absorbent and 75% with absorbent.

The nutritional value of the studied garlic genotypes is presented in Table 6 and is within the range of the values suggested by Brewster (2008) regarding proteins, carbohydrates, fat, and energy content, and Haciseferogullari *et al.* (2005) for crude protein and ash.

The concentration of carbohydrates and fats also increased which indicates the greater efficiency of fertilizers using absorbents. However, within the framework of factor A, the maximum values of carbohydrate content were reached with the application of 50% of fertilizers, with the application of 100% a significant decrease in their content was observed. The maximum fat content was observed for the application of 75% of fertilizers and a significant decrease for the application of 100%. The same trend is observed with the caloric content of products where the energy value of the product is highest in the options with 50% of fertilizers and decreases significantly with the introduction of 100%.

Discussion

Scientific substantiation of the local application of fertilizers in combination with the absorbent is an important tool for improving the productivity and sustainability of agriculture (Li *et al.*, 2019a,b).

The chlorophyll content is an important biochemical indicator of stress tolerance in plants (Percival *et al.*, 2003). Therefore, the increase in chlorophyll levels of SAP treated plants can be considered an indication that plants are not experienced with water and nutrient stress. In other words, these plants take water and nutrients sufficiently. SAP treatment increased, especially, N and Mg uptakes, allowing to form the central ion of chlorophyll and, consequently, building a darker green leaf colour (Buehner, 1956). Similar to our findings, SAP addition significantly increased the amounts of chlorophyll in cucumber (Li *et al.*, 2019a) and pepper (Sayyari, Ghanbari, 2012) plants. Moghadam (2017) reported that total chlorophyll content in the wheat plant was increased by SAP application doses (5 and 10 g per kg soil).

Our results are consistent with those of other scientists who show a decrease in the enzymatic activity with the introduction of absorbent in rapeseed (Foyer, Halliwell, 1976), corn (Habibi *et al.*, 2009), basil (Havrilyuk *et al.*, 2021). The lack of moisture (drought stress) directly or indirectly leads to the formation of oxygen radicals which leads to increased peroxidation of lipids which, in turn, can increase the formation of free radicals and cause oxidative stress (Johnson *et al.*, 2003). In our study, the superabsorbent polymer reduced the activity of these enzymes, possibly by eliminating free radicals.

The use of hydrolytic enzymes in the soil is a common approach to assessing soil quality. Enzyme activity in the soil depends on several factors. They include, for example, the content of organic matter, soil pH, the content of biogenic elements, and the quantity and condition of microorganism species (Wolinska, 2010; Bielinska, Mocek-Plociniak, 2012). According to Koper *et al.* (2004), Bielinska and Mocek-Plociniak (2012), Natywa *et al.* (2014) and Wang *et al.* (2020), the cultivation system, as well as various agrotechnical procedures, such as the correct crop rotation, the amount and type of fertilization, and the species and cultivar of crops, also have a great influence of the enzymatic activity and thus the fertility of the soil. As shown in Table 4 and Figure 2, the activity of enzymes in the soil with increasing fertilizer rate increased from 50% relative to the control with 100% scatter, but decreased significantly with the application of absorbents, which can be explained by improved water regime and soil stabilization. High activity of dehydrogenases in objects with higher nitrogen fertilization might have resulted from higher concentration of root exudates secreted by the root system of garlic.

Consistent with our findings the positive effects of SAPs applications on plant weight, height, and yield in cucumber, pepper, tomato, and soya bean are shown (Maboko, 2006; Yazdani *et al.*, 2007; Sayyari, Ghanbari, 2012; Başak *et al.*, 2016; Li *et al.*, 2019b). The increases in plant growth and yield by SAP treatment can be attributed to the presence of a sufficient amount of water and nutrients which can be easily taken with low pressure in the root area.

The local application of fertilizers improves the availability of NPK in the root zone which increases the absorption of nutrients by the plant. The studies show that such an increase in nutrients contributes to the accumulation of plant biomass due to greater intensity of photosynthesis (Chen *et al.*, 2018). However, excess fertilizers can lead to low water availability for plants due to high osmotic conditions in the soil (Studer *et al.*, 2007), but this can be compensated by absorbents that will help evenly provide plants with easily accessible moisture and nutrients.

The use of superabsorbent polymer improves plant growth. For example, the total amount of raw cucumber biomass (*Cucumis sativus L.*) and fruit biomass increased with the addition of 2% absorbent to the substrate mixture by 840 and 494 g^{-1} per plant, by Montesano *et al.* (2015). Another study with different varieties of potatoes (*Solanum tuberosum L.*) found an increase in tuber yield using superabsorbents locally in the furrows to a depth of 25 cm^{-1} (Salavati *et al.*, 2018). A similar result was found with the application of 60 and 90 kg ha^{-1}, which increased the yield of potatoes by 38.2 and 50.5% relative to the control when applying superabsorbents to a depth of 20 cm (Hou *et al.*, 2017). Although the use of superabsorbents can improve plant growth, the depth of its use can significantly affect its effectiveness.

In conditions of insufficient moisture, superabsorbents have a greater impact on plant productivity (Fazeli Rostampour *et al.*, 2013; Eneji *et al.*, 2013). The dry matter of sorghum (*Sorghum bicolor L.* Moench) increased only when there was a shortage of water in the sandy loamy soil (Fazeli Rostampour *et al.*, 2013). Similar results were obtained with beans (*Phaseolus vulgaris L.*) grown with superabsorbents (Satriani *et al.*, 2018). The use of absorbent materials has increased the yield of Citrus limon (Pattanaaik *et al.*, 2015), and coffee plants (Pieve *et al.*, 2013).

Conclusion

In the variants with local application and increasing fertilizer rate, the activity of the analyzed enzymes increased relative to control. The intensity of biochemical processes in the soil depended on the type of enzyme which is associated with the individual sensitivity of the enzyme to environmental factors and the content of minerals for the enzymatic reaction in the soil. The activity of dehydrogenase increased with increasing levels of fertilizers, including nitrogen. However, the use of absorbents contributed to the stabilization of the soil environment, increasing the availability of nutrients and, accordingly, reducing the activity of enzymes of one variant without absorbent.

To use fertilizers more efficiently and improve soil fertility it is advisable to apply fertilizers locally in rows immediately before or during the planting of garlic.

When growing garlic for food purposes (with or without absorbent) and saving fertilizers up to 50% they should be applied in the norm $N_{120}P_{60}K_{60}$ kg ha^{-1} which will ensure the formation of garlic yield at 11.8 t ha^{-1} (without absorbent) and 15.0 t (with absorbent).

To grow garlic for processing and to obtain the maximum yield in the Right-Bank Forest-Steppe of Ukraine the fertilizers should be applied locally at the rate ($N_{240}P_{120}K_{120}$ kg ha^{-1}) which will ensure crop yield of 13.1 t ha^{-1} (without absorbent) and 17.0 t ha^{-1} (with absorbent).

SAP application increased growth, yield, leaf chlorophyll, and nutrient composition contents. This increase did not only have a positive effect on plant development but also made plants more tolerant to the stress conditions.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

VY, NV, SP – study conception and design;
VY, NV, OL, VK – acquisition, analysis, and interpretation of data;
VY, SP, IM – revision, and approval of the final manuscript.

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