Caspian Journal of Environmental Sciences
Online ISSN: 1735-3866
Print ISSN: 1735-3033

Possibility of reducing the doses of mineral fertilizers in the cultivation of industrial crops

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ABSTRACT

This article explores efficient strategies for sustainable agricultural chemicalization, aiming to enhance crop yields while minimizing mineral fertilizer and pesticide use. It presents an analysis of long-term studies on human- and animal-safe bionutrients synthesized using triethanolammonium salt of orthocresoxyacetic acid and 1-chloromethylsilatrane. Research indicates that high industrial crop yields can be achieved without escalating mineral fertilizer and pesticide inputs. Treating flax seeds and plants with these bionutrients resulted in increased seed yields, attributed to improved germination energy and seed germination, without additional fertilizer. Similarly, flax straw yield increased by 18-20%. These bionutrients also suppress fungal diseases, potentially reducing or eliminating pesticide reliance. Consequently, silatranes and other organosilicon compounds offer promise as crucial elements in eco-friendly agricultural technologies, enhancing plant metabolism, improving nutrient utilization from mineral fertilizers, and decreasing pesticide dependence.

Keywords: Bionutrients, Chloromethylsilatran, Mineral fertilizers, Minimization, Flax.
Article type: Research Article.

INTRODUCTION

By the early sixties of the last century, there were 5 kg of chemical products used in agriculture per capita, 0.74% of the total number of children with genetic abnormalities were born. By the end of the eighties, the mass of chemicals entering the country's farmlands had increased to 25 kg per capita. The number of children born with genetic disorders has increased to 16.5%. Biologists have long established that a population that is 30% "corrupted" genetically is doomed to degeneration. The problems associated with the intensive use of mineral fertilizers are as follows:

Nitric: nitrates (MPC for water is 10 mg L^{-1}, for food products - 500 mg day^{-1} per person) are restored in the body to nitrites, which cause metabolic disorders, poisoning, deterioration of the immunological status, methemoglobin (oxygen starvation of tissues; Kuzyakov 1997; Chen 2016). When interacting with amines (in the stomach), nitrosamines are formed - the most dangerous carcinogens (Efremova 2020).

In children it can cause tachycardia, cyanosis, loss of eyelashes, rupture of alveoli. In animal husbandry: vitamin deficiency, decreased productivity, accumulation of urea in milk, increased morbidity, decreased fertility (Rijk & Ekblad 2020; FAO 2021).

Phosphorous: (superphosphate and fluorine, cadmium, and other heavy metals contained in it): Its excess in drinking water (more than 2 mg L^{-1}) causes damage to human tooth enamel and loss of elasticity of blood vessels. At a content of more than 8 mg L^{-1}, osteochondrosis occurs (Sinha 1997, Chenglong & Ming 2016).

Chlorine-containing fertilizers: (potassium chloride, ammonium chloride): Consumption of water with a chlorine content of more than 50 mg L^{-1} causes poisoning (toxicosis) of humans and animals (Jayaraj 2016).

Caspian Journal of Environmental Sciences, Vol. 24 No. 1 pp.107-116 Received: Aug. 22, 2025 Revised: Nov. 16, 2025 Accepted: Dec. 07, 2025
DOI: 10.22124/cjes.2026.9502

Publisher: University of Guilan,

Research by leading agricultural institutes and scientists at the Timiryazev Russian State Agrarian University has shown that, under certain conditions, it is possible to significantly reduce the use of mineral fertilizers by increasing the utilization rate of their nutrients without reducing yields, but while increasing the profitability of production (Saidasheva 2020; Shirokov 2020; Shirokov 2023).

Phytohormones: are an exceptionally effective form of intercellular regulation, without which a plant organism is doomed to inevitable death. The hormonal system of plants includes 5 groups of phytohormones: indole auxin, gibberellins, cytokinins, abscisins and ethylene (Jayaraj 2016; Rijk 2020). Auxins activate root formation. They are necessary for cell division, growth and differentiation.

Potassium salts: of indolylacetic and naphthylacetic acids are highly soluble in water, and their high stability is observed in an alkaline environment. To accelerate the growth of stems, indolylacetic acid is needed at a concentration of 10^{-6} M, for roots 10^{-11} M. Before planting, green cuttings are 1/3 immersed in a solution of naphthylacetic acid (2-25 mg L^{-1}) and kept in it for about 10 hours. Gibberellins stimulate the growth of stems, petioles and veins. Now more than 60 of their varieties have been discovered. The gibberellin content in tissues varies widely, from 0.01 to 1.4 mg per 1 kg of crude weight. Some biennial plants under the influence of gibberellin form arrows in the first year of life, which is of particular interest to breeders. The effect of light and low temperatures, necessary to remove dormant buds and seeds from dormancy, can be successfully replaced by treatment with (0.001% solution) water containing soluble salts of gibberellic acid. In recent years, organo-mineral products have been synthesized, which in their action in microdoses are similar to natural auxins and giberlins, and at the same time are absolutely harmless to humans, animals and the environment. These are 1-chloromethylsilatran and the triethanolammonium salt of orthocresoxyacetic acid. The aim of the work is to study the possibility of increasing the yield of industrial crops (using flax as an example) without increasing the doses of mineral fertilizers due to bionutrients based on organosilicon compounds that are safe for humans and animals.

MATERIALS AND METHODS

The effectiveness of the use of 1-chloromethylsilatran and the triethanolammonium salt of orthocresoxyacetic acid, which have auxin activity, both as independent bionutrients and in combination with each other, has been shown. The research methodology is based on conducting field experiments in industrial crops (flax) for processing seeds and vegetative plants, both individually and in combination. Further, to simplify, we designate the bionutrients 1-chloromethylsilatran with the letter C, the triethanolammonium salt of orthocresoxyacetic acid with the letter T and their combinations with CT. Active ingredients: Preparation form: light yellow crystalline powder with a faint peculiar odor. The content of DV is 99.6%, tablets 0.1 g of DV. Chemical name of the active substance: 1-chloromethylsilatran. Its structural formula is shown in Fig.1.

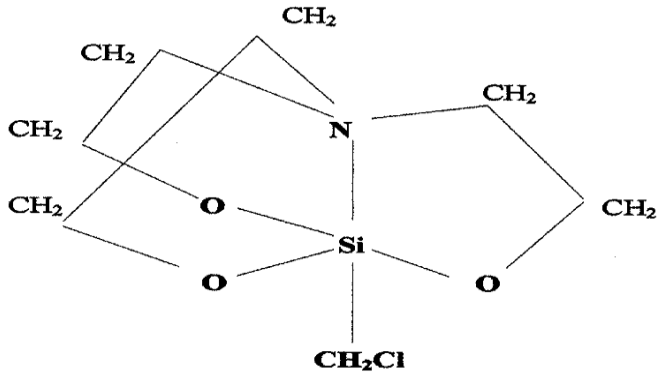

Fig. 1. The structural formula of 1-chloromethylsilatran.

The second component: cresoxyacetic acid triethanolamine salt ortho, molecular weight 539.1; its structural formula is shown in Fig. 2.

The combination of the components used (1-chloromethylsilatran 80% and triethanolamine salt of ortho-cresoxyacetic acid -20%) is conventionally called a "PRODUCT". Physico-chemical properties: hygroscopic, well soluble in water, alcohol, DMSO. The melting point is 82-85 °C. Thermally stable up to 130 °C. Toxicology: non-toxic. LD_{50} = 2300 mg kg^{-1}. Hazard class IV B. It has no mutagenic, teratogenic, cumulative or carcinogenic properties. It is not phytotoxic, has no irritating effect on mucous membranes and skin. It rapidly decomposes in

water, soil, animal organisms, and plants. The maximum concentration in the water of reservoirs is 0.1 mg L^{-1}, the maximum concentration in the air of the working area is 8 mg m^{-3}. The PRODUCT is used in the form of freshly prepared aqueous solutions. The mechanism of action of auxin type with manifestations of adaptogenic and thermoprotective effects. The concentration of components in the "PRODUCT": 190 g kg^{-1} 1-chloromethylsilatran + 760 g kg^{-1} triethanolammonium salt of orthocresoxyacetic acid. Purpose: An immunoprotector and growth regulator for the treatment of seeds and crops of agricultural crops (in particular, flax) in order to increase their yield and resistance to diseases and other stress factors. Culture: Flax is a long-lived flax. Grade: A-93.

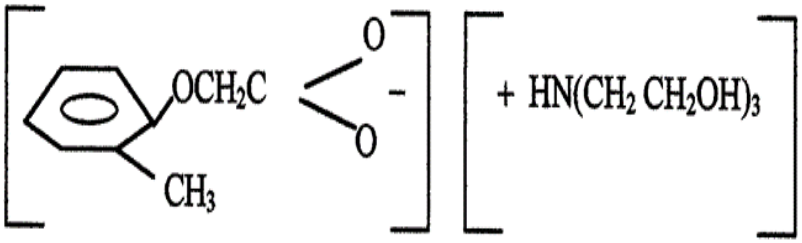

Fig. 2. The structural formula of the triethanolamine salt of orthocresoxyacetic acid.

The seeding rate: Estimated at 18 million units ha^{-1}. Place of experiments: Tver region, Torzhok district Soil-climatic zone: 1st zone of sod-podzolic soils of the Taiga forest regions, Central and Volga-Vyatka districts. Harmful objects: Flax diseases [anthracnose (ex. *Colletotrichum lini* Manns et Bolley), mottling /ozoniosis/ (b. Ozonium vinogradovi Kudr.), bacteriosis (b. *Bacillus macerans* Schr.), cloudy /septoria/ (b. *Septoria linicola* Gar.). The phase of pathogen development at the time of treatment: During seed treatment, dormant phases [spores, mycelium modifications], during crop treatment, dynamic phases of development [conidia, aerial mycelium]. The germination energy and germination of seeds are shown in the “Test results” section (Table 3).
The phase of plant development at the time of each treatment: Seeds and the” herringbone" phase of flax. Types of experiments: Small-scale and industrial. Agrotechnics of experimental plots:
The soil: Sod-podzolic, medium loamy, content of P_2O_5 - 140, K_2O - 125 mg kg^{-1}, pH = 4.8.
Precursor: Spring barley.
Tillage: Autumn - winter plowing to the depth of the arable layer, spring - cultivation, harrowing.
Fertilizers: Not applied directly to flax.
Measures for the care of experimental plots: They are variously indicated in the experimental schemes.
Meteorological data: During the growing season.

Table 1. On the day of the spraying of crops in June 17; (i) Air temperature (average; °C) +17.2; (ii) Relative humidity (%) 58; (iii) Wind speed (m sec^{-1}) 2; (iv) The precipitation time after processing is three days. Extreme weather conditions - did not occur during the growing season. The size of the plot is the accounting area in the small-scale experiment of 25 m^2, in the production of 1 ha. The placement of plots is randomized. Repeat rate: 4-fold.

Technology of application of the studied drug

Processing period: seeds before sowing (May 10), crops in the “herringbone” flax phase (June 17);
The frequency of processing: once (seeds and crops);
Method of application: (a) treatment of seeds with suspensions of preparations [with the addition of the Na CMC film-forming agent in a small-scale experiment and without it in production conditions; (b) spraying of crops with working solutions of Product compositions containing herbicides (lenok + hunter);
The equipment used: (a) manual pickling machine; (b) knapsack sprayer;
Working fluid consumption: (a) for seed treatment: 5 L ton^{-1}; (ii) for crop treatment: 200 L ha^{-1};
Experimental schemes.

Table 2. Accounting for harmful objects.
Registration dates: (a) germination diseases - May 30; (b) flax diseases in the ripening phase - August 23.
Date of appearance of diseases: May 29.

Accounting methodology: in accordance with the "... guidelines for testing fungicides, antibiotics and seed protectants..." Crop accounting; (a) Method of harvesting and accounting for crops: manual flax milling [with knitting into sheaves] from the entire accounting area of each experimental plot, drying of sheaves, threshing, cleaning of seeds; continuous crop accounting with recalculation of the mass of PRODUCT after weighing for 100% purity, 12% seed moisture and 19%-low humidity of flax straw; (b) Harvest date: August 25. The period of protective effect of the drug: prolonged throughout the growing season [due to the effect on plant immunity].

Table 1. Meteorological conditions of the growing season in 2024 (according to the Torzhok meteorological station of the Tver region).

Indicators	**Months and decades**									
	May			**June**			**July**			**August**
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**
Air temperature (°C)										
a) Average long-term	9.0	10.7	12.3	13.6	14.8	15.8	16.8	17.2	17.1	16.7
b) The current year	11.5	10.4	11.9	13	17.6	15.9	16.2	20.4	19.6	19.4
	Precipitation (mm)									
a) Average long-term	13.8	15	17.2	23.2	23.9	25	28.2	26.6	31.2	28
b) The current year	0.0	16.8	45.3	60.3	1.1	10.8	9.1	23.1	52.1	15.3
Air humidity (%)	48	67	72	75	64	65	67	73	74	73
Soil moisture in a layer of 0-10 cm (%)	12.7	19.9	23.1	24.4	17.1	18.4	15.8	18.2	24	19.3

RESULTS AND DISCUSSION

Laboratory germination and infection with flax seed diseases, depending on their treatment with preparations PRODUCT, Albit, Phenoram Super /standard mordant in a small-scale experiment/and TMTD/ standard (tetramethylthiuram disulfide) in a production experiment / in various consumption rates and mixtures, are shown in Table 3. The effectiveness of seed treatment with the above-mentioned preparations in the field against anthracnose of flax seedlings are presented in Table 4, against mottling (ozoniosis) in Table 5 and bacteriosis in Table 6. The effect of the preparations PRODUCT and fundazole/standard fungicide/ on the treatment of flax crops in comparison with the control without treatment of crops and standard chemical treatment on various backgrounds of seed treatment - against flax pasmo (septoria), manifested at the end of the growing season are shown in Table 7. The effects of plant protection products on field seed germination and stem density are shown in Table 8, and on the yield of straw and flax seeds in Table 9.

Additional information about the effect of a pesticide on harmful and related objects. There was no phytotoxic or any other negative effect of the PRODUCT and its mixtures with other pesticides on flax plants. Field experiments (including in production conditions), performed in 2024, showed the fungicidal and bactericidal effect of PRODUCT, which significantly reduces the harmful manifestation of flax seed and seedling diseases due to seed treatment with this drug at consumption rates of 0.02-0.03 kg ton^{-1}. It has also biological effectiveness against flax anthracnose in cases of the addition of the film-forming substance Na CMC [Na CMC (sodium carboxymethylcellulose) — sodium salt of cellulose glycolic acid]: 72.7 - 77.3% (without film-forming agent - 65.0%), against mottling (76.9 - 79.5% and 45.8%), against bacteriosis (66.7- 70.0% and 62.1%) respectively. The effectiveness of PRODUCT against fungal diseases of flax seedlings (anthracnose and mottling) approached the indicators of the chemical systemic mordant Phenoram Super in a small-scale experiment and the traditional TMTD preparation in production conditions, and against bacterial diseases the new drug exceeded the level of these standards (Tables 4, 5, and 6). Spraying flax crops in the "herringbone" phase with PRODUCT (0.01 kg ha^{-1}; mixed with herbicides) ensured the effectiveness of protection against pasmo (septoria) of the crop (manifested during its maturation phase) at almost the level of a standard mixture of herbicides with fundazol fungicide (1.0 kg ha^{-1}; Table 7). The obtained results are based on flax straws. Field experience with plots of 25 m^2. Treatment of plants during vegetation with a growth regulator PRODUCT (without pre-sowing seed treatment) increases straw harvest from 21 c ha^{-1} under control to 34 c ha^{-1} (61.9%). At the same time, the standard treatment of plants with a fungicide (Fundazole) increases the straw harvest to 32 kg ha^{-1}, or 2 kg ha^{-1} less (with NSR 2, the difference is within the accuracy of the experiment).

Table 2. Schemes of experiments on the establishment of biological regulations for the use of the drug MIVAL-AGRO in the flax crop [general numbering of variants] 2024).

Seed treatment option	Preparation	Consumption rate	Options for crop treatment:			
			No. 1 Control without processing	No. 2 Standard (Fundazole, 1.0 kg ha^{-1})	No. 3 MIVAL-AGRO (0.01 L ha^{-1})	No. 4 herbicides: Lenok + Hanger
Experience with plots of 25 m^2						
1. Control (without processing)	—	—	1	2	3	4
2. Standard	Fenoram Super	2.0 kg ton^{-1}	5	6	7	8
3. Albit	Albit + on KMC	0.07 kg ton^{-1} + 0.2 kg ton^{-1}	9	10	11	12
4. MIVAL-AGRO	MIVAL-agro + on KMC	0.03 kg ton^{-1} + 0.2 kg ton^{-1}	12	14	15	16
5. MIVAL-AGRO	MIVAL-agro + on KMC	0.02 kg ton^{-1} + 0.2 kg ton^{-1}	17	18	19	20
6. MIVAL-AGRO	MIWAL-agro + Fenoram Super	0.02 kg ton^{-1} + 1.0 kg ton^{-1}	21	22	23	24
Experience with plots of 1 hectare						
1. Control (without processing)	—	—	1		2	3
2. Standard	TMTD, VSK (tiram, 400 g L^{-1})	4.5 L ton^{-1}	4		5	6
3. TMTD + MIVAL-AGRO	TMTD + MIVAL-AGRO	3.0 L ton^{-1} + 0.02 L ton^{-1}	7		8	9
4. MIVAL-AGRO	MIVAL-AGRO	0.03 L ton^{-1}	10		11	12

Table 3. Laboratory germination and disease infection of flax seeds depending on their treatment with various preparations, 2024).

Processing options	Germination (%)	Infection rate (%)			
		general	including: anthracnose	mottling	bacteriosis
Experience with plots of 25 m^2					
1. Control (without processing)	75.5	38.5	10.5	17	11
2. Phenoram Super (2.0 kg ton^{-1})	76	14	2	3.5	8.5
3. Albit (0.07 kg ton^{-1}) + NA CMC (0.2 kg ton^{-1})	76.5	15.5	5	6.5	4
4. MIVAL-AGRO (0.03 kg ton^{-1}) + Na CMC (0.2 kg ton^{-1})	77	14	4.5	6	3.5
5. MIVAL-AGRO (0.02 kg ton^{-1}) + NA CMC (0.2 kg ton^{-1})	77.5	15	5	6	4
6. MIVAL-AGRO (0.02 kg ton^{-1}) + Phenoram super (1.0 kg ton^{-1})	78	6.5	1.5	2	3
L ±	2.1	0.5	0.1	0.2	0.1
Experience with plots of 1 hectare					
1. Control (without processing)	79	23	4.5	8.5	10
2. Standard: TMTD, VSK (Tiram, 400 g L^{-1}), 4.5 L ton^{-1})	79	13.5	2.5	3.5	7.5
3. TMTD, 3.0 (L ton^{-1}) + MIVAL-agro, 0.02 (kg ton^{-1})	80.5	8	2.5	3	2.5
4. MIVAL-agro (0.03 kg ton^{-1})	80.5	9	3	3.5	2.5
L ±	2.2	0.4	0.1	0.2	0.2

The data obtained suggest that flax responds well to foliar treatments with PRODUCT and may well replace the treatment with Fundazole. At the same time, a new product, unlike Fundazole, it is harmless to humans, animals and insects. By standard seed treatment with the fungicide Phenoram, the PRODUCT used for plant treatment increases straw harvest to 42 c ha^{-1} (with HCV 2), i.e., almost at the Fundazole level, where straw harvest is 40 c ha^{-1}, with a tendency to increase.

Table 4. Biological efficacy of drugs: MIVAL-AGRO, Albit, Phenoram Super and TMTD [in seed treatment] against anthracnose of flax seedlings (2024)

Processing option	The prevalence of anthracnose (%)	Biological efficiency (%)
Experience with plots of 25 m^2		
1. Control (without processing)	11.0	—
2. Phenoram Super (2.0 kg ton^{-1})	2.0	81.8
3. Albit (0.07 kg ton^{-1}) + NA CMC (0.2 kg ton^{-1})	3.5	68.2
4. MIVAL-AGRO, 0.03 kg ton^{-1} + Na CMC (0.2 kg ton^{-1})	2.5	77.3
5. MIVAL-AGRO (0.2 kg ton^{-1}) + NA CMC (0.2 kg ton^{-1})	3.0	72.7
6. MIVAL-AGRO (0.02 kg ton^{-1}) + Phenoram super (1.0 kg ton^{-1})	1.5	86.4
The smallest significant difference (0.05; ±)	0.4	
Experience with plots of 1 hectare		
1. Control (without processing)	10.0	—
2. Standard: TMTD, VSK (Tiram, 400 g L^{-1}), 4.5 L ton^{-1})	4.0	60.0
3. TMTD, 3.0 L/T + MIVAL-agro (0.02 kg ton^{-1})	2.0	80.0
4. MIVAL-agro (0.03 kg ton^{-1})	3.5	65.0
The smallest significant difference (0.05; ±)	0.4	

Table 5. Biological efficacy of the preparations MIVAL-AGRO, Albit, Phenoram super and TMTD [in seed treatment] against speckling (ozoniosis) of flax seedlings (2024)

Processing option	The prevalence of mottling (%)	Biological efficiency (%)
Experience with plots of 25 m^2		
1. Control (without processing)	19.5	—
2. Phenoram Super (2.0 kg ton^{-1})	3.0	84.6
3. Albit (0.07 kg ton^{-1}) + NA CMC (0.2 kg ton^{-1})	4.5	76.9
4. MIVAL-AGRO (0.03 kg ton^{-1}) + Na CMC (0.2 kg ton^{-1})	4.0	79.5
5. MIVAL-AGRO (0.02 kg ton^{-1}) + NA CMC (0.2 kg ton^{-1})	4.5	76.9
6. MIVAL-AGRO (0.02 kg ton^{-1}) + Phenoram super (1.0 kg ton^{-1})	2.0	89.7
The smallest significant difference (0.05; ±)	0.5	
Experience with plots of 1 hectare		
1. Control (without processing)	12.0	—
2. Standard: TMTD, VSK (Tiram, 400 g L^{-1}), 4.5 L ton^{-1}	5.5	54.2
3. TMTD (3.0 L ton^{-1}) + MIVAL-agro (0.02 kg ton^{-1})	4.5	62.5
4. MIVAL-agro (0.03 kg ton^{-1})	6.5	45.8
The smallest significant difference (0.05; ±)	—	

If we compare with Albit, then in this case (once processing only plants, when the seeds are treated with Phenoram), they work the same way (on Albit, straw harvesting is also 42 kg ha^{-1}). The highest yield of straw in the experiment was 45 c ha^{-1} (significantly higher than all experimental data), obtained by processing seeds with a mixture of PRODUCT + Phenoram Super and processing plants with a product in the "herringbone" phase. What is 45 c ha^{-1} of straw? This is more than twice as high as compared with absolute control (without seed and plant treatments: 21 c ha^{-1}); 11 c ha^{-1} or 32% higher than only when processing Plant products; 15 c ha^{-1} or 50% higher than when treating seeds with the preparation alone, and by 12 c ha^{-1} or 36% higher than when treating seeds with PRODUCT + Phenoram Super mixture. When compared with the standard (Phenoram Super seed treatment and Fundazole plant treatment), where straw collection is 40 kg ha^{-1}, the PRODUCT preparation (when included in the tank mixture during seed treatment and plant processing in the herringbone phase) increases straw collection by 5 kg ha^{-1} or 12.5%.

Table 6. Biological efficacy of the preparations PRODUKT, Albit, Phenoram super and TMTD [in seed treatment] against bacteriosis of flax seedlings (2024)

Processing Variant	The prevalence of bacteriosis (%)	Biological effectiveness (%)
Experiment on 25 m² plots of land		
1. Control (without processing)	15.0	—
2. Phenoram Super (2.0 kg ton^{-1})	10.0	33.3
3. Albit (0.07 kg ton^{-1}) + NA CMC (0.2 kg ton^{-1})	5.5	63.3
4. MIVAL-AGRO (0.03 kg ton^{-1}) + Na CMC (0.2 kg ton^{-1})	4.5	70.0
5. MIVAL-AGRO (0.02 kg ton^{-1}) + NA CMC (0.2 kg ton^{-1})	5.0	66.7
6. MIVAL-AGRO (0.02 kg ton^{-1}) + Phenoram Super (1.0 kg ton^{-1})	4.0	73.3
The smallest significant difference (0.05)	0.5	
Experience with plots of 1 hectare		
1. Control (without processing)	14.5	—
2. Standard: TMTD, VSK (Tiram, 400 g L^{-1}), 4.5 L ton^{-1}	11.0	24.1
3. TMTD (3.0 L ton^{-1}) + MIVAL-agro (0.02 kg ton^{-1})	4.5	69.0
4. MIVAL-agro, (0.03 kg ton^{-1})	5.5	62.1
The smallest significant difference (0.05)	0.4	

Table 7. The effectiveness of flax protection from cloudy (septoria), appearing in the ripening phase (2024) (General numbering of variants. Disease prevalence/biological efficacy (%)

Seed treatment option	Crop treatment No. 1 (control)	Crop treatment No. 2 (Fundazole, 1.0 kg ha^{-1})	Crop treatment No. 3 (MIVAL-AGRO (0.01 L ha^{-1})	Crop treatment No. 4 (herbicides: Lenok + Hanger, 0.005 kg ha^{-1} + 1.5 L ha^{-1})
Experience with plots of 25 m²				
1. Control (without processing)	34 / —	10 / 71	11 / 68	29 / 15
2. Standard: Phenoram Super (2.0 kg ton^{-1})	27 / 21	9 / 74	9 / 74	26 / 24
3. Albit (0.07 kg ton^{-1}) + NA CMC (0.2 kg ton^{-1})	30 / 12	9 / 74	10 / 71	28 / 18
4. MIVAL-AGRO (0.02 kg ton^{-1}) + NA CMC (0.2 kg ton^{-1})	28 / 18	10 / 71	9 / 74	26 / 24
5. MIVAL-AGRO (0.03 kg ton^{-1}) + Na CMC (0.2 kg ton^{-1})	27 / 21	9 / 74	8 / 77	26 / 24
6. MIVAL-AGRO (0.02 kg ton^{-1}) + Phenoram Super (1.0 kg ton^{-1})	25 / 26	9 / 74	8 / 77	25 / 26
Experience with plots of 1 hectare				
1. Control (without processing)	21 / —	9 / 57	17 / 19	—
2. Standard: TMTD, VSK (Tiram, 400 g L^{-1}), 4.5 L ton^{-1}	19 / 10	8 / 62	14 / 33	—
3. TMTD (3.0 L ton^{-1}) + MIVAL-agro (0.02 kg ton^{-1})	17 / 19	6 / 71	12 / 43	—
4. MIVAL-agro (0.03 kg ton^{-1})	18 / 14	8 / 62	14 / 33	—

Production experience, the area of the plot is 1 hectare. In production experience, the technology of flax cultivation provides for the use of TMTD in seed pickling. The straw harvest under absolute control (without treatment) is 35 c ha^{-1}, with TMTD seed treatment: 38 c ha^{-1}. The introduction of the tank mixture together with TMTD "PRODUCT" allows to increase the straw harvest to 44 kg ha^{-1} or by 6 kg ha^{-1}, which is 15.8%. When processing the "PRODUCT" plants (the seeds were not treated with anything), the straw harvest increases to 48 c ha^{-1}, or increases by 13 c ha^{-1} compared to the control, which is 37%. When etching TMTD seeds and processing the PRODUCT plants, straw harvest reaches 51 c ha^{-1} at 38 without treatment with the drug. The increase is 13 c ha^{-1} or 34%. The inclusion of the "PRODUCT" in flax cultivation technology (seed treatment in conjunction with TMTD + processing of vegetative plants) makes it possible to obtain a straw harvest of 54 c ha^{-1}. This is 19 c ha^{-}

[1] or 54% more than the absolute control and 16 c ha^{-1} or 42% more than with the generally accepted cultivation technology, which provides only for etching seeds of TMTD. Almost the same harvest (53 kg ha^{-1}) can be obtained from using only the PRODUCT for seed treatment (increased consumption rate of 30 g ton^{-1}) and plants in the "herringbone" phase.

Table 8. The dependence of field germination of seeds [in the germination phase] and the density of the flax stem [in the maturation phase] on the use of preparations PRODUKT, Albit, Fenoram Super, TMTD, fundazol, lenok and Hunter]

Seed treatment option	Crop treatment No. 1 (control)	Crop treatment No. 2 (Fundazole, 1.0 kg ha^{-1})	Crop treatment No. 3 (MIVAL-AGRO, 0.01 L ha^{-1})	Crop treatment No. 4 (herbicides: Lenok + Hanger)
Experience with plots of 25 m^2				
1. Control (without processing)	48 / 711	902	904	878
2. Standard: Phenoram Super (2.0 kg ton^{-1})	51 / 823	940	961	914
3. Albit (0.07 kg ton^{-1}) + NA CMC (0.2 kg ton^{-1})	53 / 830	943	968	915
4. MIVAL-AGRO, (0.02 kg ton^{-1}) + NA CMC, 0.2 kg ton^{-1}	54 / 834	947	972	919
5. MIVAL-AGRO (0.03 kg ton^{-1}) + Na CMC (0.2 kg ton^{-1})	54 / 832	948	974	916
6. MIVAL-AGRO (0.02 kg ton^{-1}) + Phenoram Super (1.0 kg ton^{-1})	55 / 841	954	980	924
Experience with plots of 1 hectare				
1. Control (without processing)	51 / 720	944	921	—
2. Standard: TMTD, VSK [(tiram, 400 g L^{-1}), 4.5 L ton^{-1}]	53 / 809	970	947	—
3. TMTD (3.0 L ton^{-1}) + MIVAL-AGRO, (0.02 kg ton^{-1})	57 / 844	983	964	—

Table 9. The effect of PRODUCT, Albit, Fenoram Super, TMTD, Fundazol, Lenok and Hunter on the yield of flax products (2024)

Seed treatment option	Crop treatment No. 1 (control)	Treatment of crops No. 2 (Fundazol, 1.0 kg ha^{-1})	Treatment of crops No. 3 (MIVAL-AGRO, 0.01 L ha^{-1})	Treatment of crops No. 4 (herbicides: Lenok + Hanger)
Experience with plots of 25 m^2				
1.Control (without processing)	21 / 1.0	32 / 1.8	34 / 2.0	30 / 1.6
2. Standard: Phenoram Super (2.0 kg ton^{-1})	30 / 1.4	40 / 2.1	42 / 2.5	34 / 2.0
3. Albit (0.07 kg ton^{-1}) + NA CMC (0.2 kg ton^{-1})	30 / 1.5	41 / 2.3	42 / 2.7	35 / 2.1
4. MIVAL-AGRO (0.03 kg ton^{-1}) + Na CMC (0.2 kg ton^{-1})	31 / 1.8	42 / 2.4	43 / 3.0	38 / 2.3
MIVAL-AGRO (0.02 kg ton^{-1}) + NA CMC (0.2 kg ton^{-1})	30 / 1.8	41 / 2.5	43 / 2.9	39 / 2.2
6. MIVAL-AGRO (0.02 kg ton^{-1}) + Phenoram Super (1.0 kg ton^{-1})	33 / 2.1	43 / 2.8	45 / 3.4	40 / 2.6
NSR$_{05}$	2 / 0.2			
Experience with plots of 1 hectare				
1. Control (without processing)	35 / 1.9	48 / 3.9	44 / 3.3	—
2. Standard: TMTD, VSK [(Tiram, 400 g L^{-1}), 4.5 L ton^{-1})]	38 / 2.4	51 / 4.3	48 / 3.9	—
3. TMTD, 3.0 (L ton^{-1}) + MIVAL-agro (0.02 kg ton^{-1})	44 / 2.9	54 / 4.8	51 / 4.4	—

The results obtained on flax seeds

Field experience with plots of 25 m^2

The highest seed yield, 3.4 c ha^{-1}, was obtained by pre–sowing seed treatment with the PRODUCT preparation together with Phenoram + treatment of vegetative plants with the PRODUCT in the "herringbone" phase. This is

significantly higher than with standard treatments (seeds – Phenoram Super, plants – Fundazole), where the seed yield is 2.1 c ha^{-1}. The increase in seed yield when using the PRODUCT for seed treatment together with Phenoram and plants in the "herringbone" phase is 1.3 kg ha^{-1} (3.4-2.1) or 61.9%. In Production experience, the area of the plot is 1 hectare. The seed yield with standard pre-sowing treatment of TMTD is 2.4 c ha^{-1}, which exceeds the control (without treatment) by 0.5 c ha^{-1} or 26%. Seed treatment with TMTD tank mixture + the PRODUCT increases seed yield by 0.5 c ha^{-1} (2.9-2.4) or 20.8% compared to treatment with only one pesticide. The seed yield when using the PRODUCT for pre–sowing seed treatment and processing of vegetative plants in the herringbone phase is 4.8 kg ha^{-1}, which is twice as high as the flax cultivation technology generally used in most farms, that includes only TMTD seed treatment (seed yield 2.4 kg ha^{-1}). Seed treatment with a product of 30 g ton^{-1} (instead of the recommended 20 g ton^{-1}) + processing of plants in the "herringbone" phase, allows us to get the same high seed yield (4.8 kg ha^{-1}) as with the combined processing of TMTD and the PRODUCT (25). Conclusions: as a growth regulator: The high biological efficiency of flax seed treatment has been shown, the PRODUCT at a dose of 20 g ha^{-1} in a tank mixture with fungicides: Phenoram+ the PRODUCT is 86.4%; Phenoram Super is 81.1%. Compared with Albit, it significantly reduces the spread of anthracnose on flax seedlings.

CONCLUSION

Field (including production) tests conducted in 2024 showed a high biological and economic effectiveness of using the drug PRODUCT on flax seed culture, in the processing of seeds and crops. The experiments also showed a pronounced growth-stimulating effect of "PRODUCT" on flax (Tables 8 and 9). When seeds were treated with it, their field germination increased by 6% (compared to the control without treatment). Spraying of vegetative flax plants with a mixture of a PRODUCT with herbicides in combination with the treatment of seeds with this preparation increased the density of the crop stem by 263 plants m^{-2}. The yield of fiber products (calculated from straw) and flax seeds significantly increased due to using PRODUCT in seed treatment (respectively: from 21 to 30-31 and from 1.0 to 1.8 kg ha^{-1}) and crops (against the background of seed treatment to 43 and 3.0 kg ha^{-1}; Table 9).

Indicators the yields of flax products in variants with PRODUCT are not inferior to the standards (with Phenoram Super, Albit and fundazole - in a small-scale experiment and with TMTD - in production conditions) and even sometimes exceed them. Field experiments (including in production conditions) performed in 2024 by the Wildebeest Research Institute of Flax of the Russian Agricultural Academy showed the fungicidal and bactericidal effect of PRODUCT, which significantly reduces the harmful manifestation of diseases of flax seeds and seedlings due to seed treatment with this drug at consumption rates of 0.02-0.03 kg ton^{-1} with its biological effectiveness against anthracnose flax in cases of the addition of the film–forming substance Na CMC 72.7- 77.3% (without the film-forming agent 65.0%), against mottling, 76.9 - 79.5% and 45.8%, against bacteriosis (66.7- 70.0% and 62.1%) respectively.

The effectiveness of PRODUCT against fungal diseases of flax seedlings (anthracnose and mottling) approached the indicators of the chemical systemic mordant Phenoram Super in a small-scale experiment and the traditional TMTD preparation in production conditions, and against bacterial diseases the new drug exceeded the level of these standards (Tables 4, 5, and 6).

The highest indicators of the effectiveness of flax protection from diseases and the results of a positive effect on cultivated plants and their yields in field experiments were obtained in connection with the treatment of seeds with the PRODUCT in a mixture with reduced consumption rates of chemicals: Phenoram Super (in a small-scale experiment) and TMTD (in production conditions) during subsequent processing of crops of the PRODUCT in a mixture with herbicides.

The inclusion of the plant bionutrient "PRODUCT" in the technology of flax cultivation allows: increasing straw collection by 12.5-15.8% compared to conventional technologies and increasing seed yield by 20% or more without the use of additional doses of mineral fertilizers.

ACKNOWLEDGMENTS

This study was carried out under agreement No. 075-15-2025-543 dated 16.06.2025

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Bibliographic information of this paper for citing:

Shirokov, YA, Mochunova, NA, Benin, D 2026, Possibility of reducing the doses of mineral fertilizers in the cultivation of industrial crops. Caspian Journal of Environmental Sciences, 24: 107-116.