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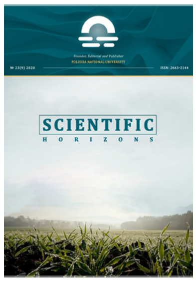

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Liquid organic-mineral fertilisers in the technology of growing winter peas

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Abstract. The issue of adapting to climate change through the expansion of crop types has sparked interest in winter peas, which can be introduced into crop rotations to stabilise the yield of legumes, positively affect soil fertility, and increase arable land productivity, but the nutrition system of winter peas needs to be investigated and

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optimised, especially considering the rising cost of mineral fertilisers. The purpose of this study was to investigate the effect of liquid organic-mineral fertilisers on the yield and quality of pea grain of winter sowing. To complete the objectives of the study, a field trial was conducted in the Odesa Oblast of Ukraine in 2021-2023. The replication of the experiment was fourfold, and the arrangement of variants was systematic. Liquid organo-mineral fertilisers were used in the experiment, which were applied once during the restoration of spring vegetation, in the budding phase and twice (restoration of spring vegetation+budding); the control variant did not involve the application of preparations. It was found that the use of liquid organo-mineral fertilisers on winter pea crops helps to increase its yield, but the growth rate is unstable, depends on weather conditions, and ranged within 0-30.4% over the years of research. The studied fertilisers had a substantial effect on the protein concentration in pea grain, the yield of which per unit area increased by an average of 22.4%, the thousand-kernel weight increased, but within the limits of statistical significance. The obtained findings suggested the possibility of using liquid organic-mineral fertilisers for growing winter peas using resource-saving or organic technology in the zone of high meteorological risks, but it should be considered that their effectiveness is determined by the composition and frequency of application. The practical value of the study lies in the development of elements of the nutrition system, which provides an increase in the yield of peas of winter sowing by 0.24-0.41 t/ha, high protein content and the level of profitability of its production – 117-152%, while the use of liquid organic-mineral fertilisers contributes to the biologisation of pea growing technology, reduces the cost of mineral fertilisers, and mitigates the chemical load on soils

Keywords: leguminous crop; weather conditions; fertilisers; productivity; grain quality

INTRODUCTION

Establishing the feasibility and effectiveness of using liquid organic-mineral fertilisers through foliar treatments of winter pea crops to ensure high yields, grain quality, and reduce the chemical load on soils determines the relevance of the study. L. Wilson *et al.* (2021) noted that the world is facing the problem of climate change and, against the background of rising average annual temperatures, changes in the spatial distribution of precipitation, the frequency of extremely high temperatures is increasing, especially in the South and South-East of Ukraine. This, as noted by N.B. Zakorchevna and Yu.S. Demidyuk (2021), requires a flexible and effective response from the agricultural sector of Ukraine to current and future variations in agrometeorological indicators through the reorientation of crops typical for the zone, optimisation of their cultivation technologies, and the introduction of new plant species and types.

The research is also stimulated by the fact that, according to H. Ferreira *et al.* (2021) and B. Carlini *et al.* (2024), the production of leguminous crops is one of the priority areas for improving protein security in the European Union, and for Ukraine, the growth of leguminous crops production means an increase in exports and strengthening the country's financial condition and economic independence. Pea (*Pisum sativum* L.) is one of the key legumes, and its grains and products are one of the main sources of protein for humans and animals (Semba *et al.*, 2021), since, unlike cereals, it accumulates up to 35% of protein, depending on the variety and growing conditions. The protein of pea grain has a high nutritional value and, as shown in the studies of S. M. Romanov and L. Storozhyk (2023), the amino acid content in winter pea grain was 21.04-21.34% or 87.7-88.9% of the total protein of 24.0%, with the share of essential amino acids prevailing.

Winter sowing of peas is of great interest to scientists and agricultural producers, as global warming has led to certain changes in the timing of the seasons: winters have become 1-3°C warmer and spring is coming earlier. V. Sichkar and R. Solomonov (2019), V. Sichkar *et al.* (2023) showed the advantages of winter sowing of peas: productive use of winter-spring soil moisture reserves, earlier maturation by 15-20 days compared to spring sowing, which makes it possible to carry out repeated sowing. Current research suggests that in the southern steppe zone, sowing is best done in the second half of October, as seedlings bearing 4-5 leaves are the most frost-resistant, and even when the weather is dry in autumn and seedlings do not emerge before the frost, the seedlings emerge together in spring and the plants develop without any deviations.

Considering the significance of peas, the Odesa State Agricultural Research Station is working to investigate and improve the nutrition system for winter peas as one of the key elements of its cultivation technology. A. Virtanen and H. Linkova (1946) reported the active use of organic amino acids by peas as a source of nitrogen, while V.P. Karpenko and Y.O. Boiko (2019) in a vegetation experiment on plants of winter peas of the NS Moroz variety showed an increase in their stress resistance to negative growing conditions when sprayed with a solution of Agroflex-Amino (1 kg/ha), which is a complex of free L-amino acids of 50% plant origin. The condition of the plants improved due to an increase in photosynthetic activity, as a week after the treatment, the content of chlorophylls increased by 24.8%, carotenoids – by 20.4%, furthermore, L-amino acids are easily available for protein synthesis.

With the establishment and growth of the market for microbial and preparations based on extracts from plants, seaweed, organic materials, as well as intra-complex compounds based on organic amino acids, fullerene or ethylenediaminetetraacetic acid (EDTA), which have stimulating properties and enhance mineral nutrition of crops, their effectiveness was also studied on pea crops and positive results were obtained. O.V. Averchev and T.S. Kovshakova (2022) found high physiological activity of the preparation "Helafit" and a mixture of boron and molybdenum when used in the phase of anthesis and budding on crops of three varieties of spring peas, which was manifested in an increase in the growing season from 4 to 6 days. According to the experiments of O.A. Kovalenko (2021), the yield of peas after treatment of seeds before sowing with Nanomix microfertiliser increased by an average of 240 kg/ha.

Trace elements have been found to affect nodule formation and nitrogen fixation: boron is required for nodule maturation; copper – for nitrogen fixation in rhizobia; iron – for several key enzymes of the nitrogenase complex, as well as for electron transfer of ferredoxin and some hydrogenases; and since molybdenum is a metal component of nitrogenase, all nitrogen-fixing systems have a specific high demand for molybdenum. When analysing the results of microfertiliser use, O.M. Vuiko (2022) emphasised that molybdenum and boron improve the nitrogen supply to pea plants and the yield increase from the application of these elements together can be 200-400 kg/ha, while copper and zinc can increase the yield by an average of 300 kg/ha.

Thus, trace elements have become a necessary component of various stimulating and nutritional preparations tested on pea crops, mostly spring peas. However, the effectiveness of fertilisers on winter pea crops is understudied, especially in terms of regulations for their use based on specific soil and climatic conditions. The purpose of this study was to establish the timing and frequency of use of liquid preparations of various origins, which include trace elements Mo, B, organic nitrogen in the form of amino acids, on pea crops of winter sowing.

MATERIALS AND METHODS

Weather conditions in the years of research. The experiments were conducted on the experimental fields of the Odesa State Agricultural Station of the Institute of Climate Oriented Agriculture of the National Academy of Agrarian Sciences of Ukraine. Odesa region is located in the Southern Steppe zone of Ukraine, which is characterised by frequent droughts, high air temperatures, and uneven distribution of rainfall. The duration and nature of weather conditions during the years of research differed significantly in terms of temperature, rainfall, and its distribution during the growth and development of winter pea plants (Fig. 1). There was a difference in the amount of precipitation and rainy days between September and full ripeness (20 June): 434 mm in 2021, 211.6 mm in 2022 and 375.5 mm in 2023, with 64, 38, and 57 rainy days, respectively (Fig. 1a).

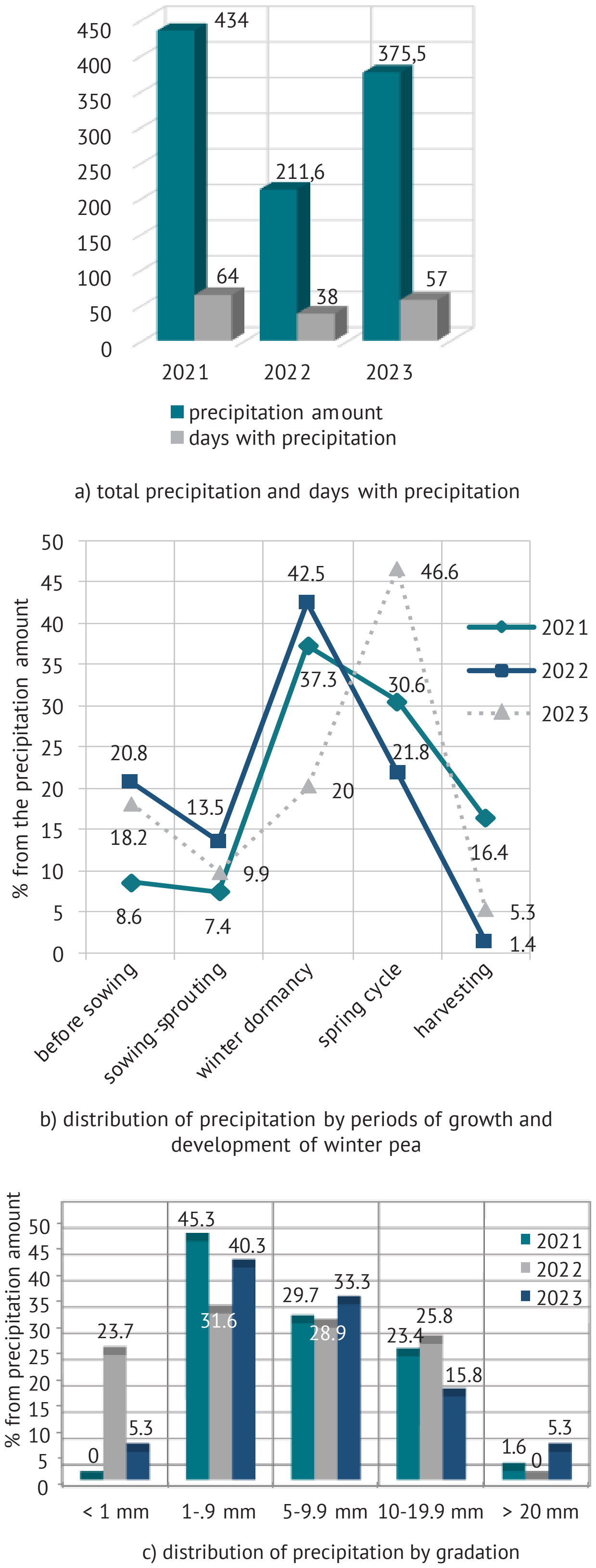

***Figure 1**. Characteristics of moisture availability in the years of research*
***Source:** data from the Odesa meteorological station of the State Emergency Service of Ukraine, systematised and processed by the authors of this study*

During the entire period of observation, both the pre-sowing period and the period from sowing to germination were insufficient in terms of rainfall. The worst year for this indicator was 2021, when precipitation was only 8.6% of the total (Fig. 1b). Winter precipitation accounted for the largest share of total precipitation in 2022 (42.5%), while in 2023 it was the smallest (20.0%). During the spring growing season, the worst year of all was 2022: during three months, the plants received only 46.1 mm of precipitation, which was only 21.8% of the total. However, in 2023, the spring moisture supply was at its highest level, with 176 mm of precipitation (46.6% of the total) from March to May, which contributed to the formation and ripening of grain.

Precipitation received by pea plants during the period of growth and development was also characterised by different quality (gradations). The year 2022 had the worst ratio of unproductive (less than 1 mm per rainfall) and low-productive precipitation (up to 5 mm): it accounted for 55.3% of the total (Fig. 1c). The air temperature in all years and throughout the growing season exceeded the climatic norm (Fig. 2), which confirms the warming trend in the study area.

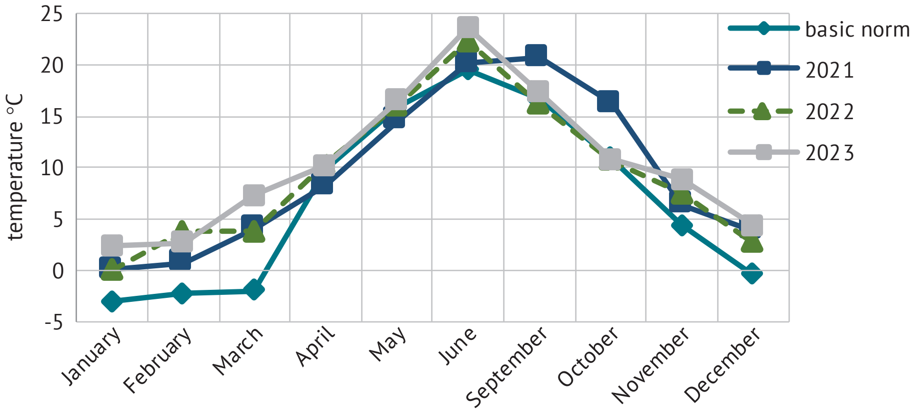

***Figure 2**. Average monthly air temperature in the years of research*

***Source:** data from the Odesa meteorological station of the State Emergency Service of Ukraine, systematised and processed by the authors of this study*

The soil of the experimental field is a southern low-humus heavy loamy chernozem on loess-like deposits with the following agrochemical characteristics of the arable layer: humus content – 3.71%, nitrification capacity according to Kravkov – 11.2 mg/kg; the content of available P_2O_5 and K_2O (according to Machigin) – 93.1 mg/kg and 312.8 mg/kg, respectively, which corresponds to the increased and high level of provision of these macroelements. The topsoil of the experimental field had a high content of manganese (9.74 mg/kg), cobalt (0.20 mg/kg), and copper (0.30 mg/kg), but low zinc (0.94 mg/kg) and medium molybdenum (0.09 mg/kg). The concentration of trace elements was determined in an ammonium acetate extract with a 4.8 pH, except for Mo (oxalate-buffered solution with a 3.3 pH); the content of heavy metals cadmium and lead did not exceed the maximum permissible concentrations (MPC): Cd – 0.03 mg/kg with a MPC of 2.0 mg/kg; Pb – 1.62 mg/kg with a MAC of 6.0 mg/kg (Methodology of agrochemical certification of agricultural lands..., 2019).

Liquid organo-mineral fertilisers (LOMF) produced by Tradecorp (Spain) were used in the experiment: *Tradefos B-Mo* is a fertiliser based on phosphorus (339 g/l) and potassium (319 g/l), enriched with molybdenum (7 g/l) and boron (14 g/l); *Tradebor Mo* contains boron in the form of ethanol amine (105 g/l) and molybdenum (12 g/l); *Phylgreen B-Mo* is made based on *Ascophyllum nodosum* algae extract, enriched with boron (120 g/l) and molybdenum (10 g/l); *Delfan plus* is a solution of L-£ amino acids obtained by acid hydrolysis of animal products containing 108 g/l of organic nitrogen. The scheme of the experiment is presented in Table 1.

***Table 1**. Scheme of LOMF use*

Var.	Preparation	Application rate, l/ha	Development stage	
			spring vegetation recovery (SVR) (30-31)	budding (B) (51-55)
1	Control	–	–	–
2	Tradefos B-Mo	4.0	+	–
3			–	+
4			+	+
5	Tradebor Mo	2.5	+	–
6			–	+
7			+	+

Table 1. Continued

Var.	Preparation	Application rate, l/ha	Development stage	
			spring vegetation recovery (SVR) (30-31)	budding (B) (51-55)
8	Phylgreen B-Mo	2.0	+	–
9			–	+
10			+	+
11	Delfan plus	3.0	+	–
12			–	+
13			+	+

Source: *developed by the authors of this study*

The replication was fourfold, the area of the elementary plot – 20 m2, and the accounting plot – 15 m2. The experiments were designed according to the recognised methods of setting up field experiments. Soil cultivation – multi-depth, generally accepted for the rainfed conditions of the Southern Steppe. Peas of the Enduro variety were sown in the second decade of October, and the harvest was recorded in the beginning of the second decade of June. Harvesting was carried out by a Sampo-130 combine harvester (Finland) in plots with grain samples taken for analysis. The protein content of pea grains was determined by infrared spectroscopy using a Spectran-119 M (Ukraine) (DSTU 4117:2007, 2007), and the thousand-kernel weight (DSTU 4138-2002, 2004). The statistical processing of the research results was carried out using generally accepted methods in crop production (Ermantraut *et al.*, 2007; Ushkarenko *et al.*, 2008). Mathematical and statistical methods of analysis, logical and theoretical analysis were used. Experimental studies of plants (both cultivated and wild), including the collection of plant material, were performed following the institutional, national, or international guidelines. The authors of this study followed the standards of the Convention on Biological Diversity (1992) and the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

Yield of peas of winter sowing using ROMD. Fluctuations in weather conditions over the years of research have affected the yield of winter peas. The average yield for the experimental variants by year was 3.42 t/ha in 2021, 1.31 t/ha in 2022, and 2.68 t/ha in 2023. The correlation analysis showed a very high dependence of the yield on the total moisture supply of the growing season (r = 0.94), a high dependence on the accumulation of moisture at the time of the resumption of spring vegetation (r = 0.89) and an average dependence on the amount of precipitation during the sowing – sprouting period and during the period of active spring vegetation (r = 0.62-0.66). Overall, the share of precipitation before the germination period and spring vegetation was 22.8% and 25.9%, respectively, and precipitation from the end of the growing season to the resumption of vegetation was 51.3%. The calculations showed that for every 1 mm decrease in precipitation during the growing season and in May, the grain yield of winter peas decreased by an average of 14.6 kg/ha. Precipitation in June, which occurred during the last period of grain ripening, had a weak negative impact on grain yield (r = -0.40). The increase in temperature during the entire period from the resumption of spring vegetation negatively affected the level of productivity (r =/-0.54/–/-0.89/), the greatest impact on the value of productivity was made by the average monthly temperatures of April (r = -0.79) and June (r = -0.89). In the weather conditions of 2021, the treatment of pea crops with Tradefos B-Mo solution during the renewal of vegetation did not significantly affect the crop yield compared to the control (Table 2); more effective was the treatment in the budding phase and in both phases, when the growth was 0.45 t/ha and 0.55 t/ha with $LSD_{0.95}$ = 0.23.

Table 2*. Grain yield of winter peas by variants of LOMF application by years of research*

LOMF	Processing phase	Yield, t/ha				± to control			
						t/ha			
		2021	2022	2023	mean	2021	2022	2023	mean
Control	–	3.05	1.23	2.27	2.18	–	–	–	–
Delfan plus	VVV*	3.40	1.23	2.64	2.42	0.35	0	0.37	0.24
	B**	3.54	1.33	2.92	2.60	0.49	0.10	0.65	0.41
	SVR+B***	3.68	1.38	2.70	2.59	0.63	0.15	0.43	0.40
Tradefos BMo	SVR	3.24	1.42	2.58	2.41	0.19	0.19	0.31	0.23
	B	3.50	1.31	2.68	2.50	0.45	0.08	0.41	0.31
	SVR+B	3.60	1.35	2.51	2.49	0.55	0.12	0.24	0.30
Tradebor Mo	SVR	3.72	1.31	2.43	2.49	0.67	0.08	0.16	0.30
	B	3.23	1.28	2.61	2.37	0.18	0.05	0.34	0.19
	SVR+B	3.53	1.42	2.48	2.48	0.48	0.19	0.21	0.30

Table 2. Continued

LOMF	Processing phase	Yield, t/ha				± to control t/ha			
		2021	2022	2023	mean	2021	2022	2023	mean
Phylgreen BMo	SVR	3.28	1.23	2.84	2.45	0.23	0	0.57	0.27
	B	3.35	1.24	2.96	2.52	0.30	0.01	0.69	0.34
	SVR+B	3.38	1.26	2.80	2.48	0.33	0.03	0.53	0.30
$LSD_{0.95}$		0.23	0.04	0.15		0.23	0.04	0.15	

Notes: ** – spring vegetation recovery; ** – budding; *** – spring vegetation recovery + budding Phases of foliar fertilisation – * spring vegetation recovery; ** – budding; *** – spring vegetation recovery + budding*
Source: *compiled by the authors of this study based on conducted research*

The use of Tradebor Mo was significantly effective at an earlier stage of pea plant development, with a yield increase of 22.0% or 0.67 t/ha; the preparation based on seaweed extract (Phylgreen B-Mo) provided small increases from 0.23 t/ha to 0.33 t/ha, depending on the timing and frequency of treatment. The twofold treatment with Delfan plus increased the yield of winter peas by 0.63 t/ha (20.6%). In 2022, organo-mineral fertilisers enriched with boron and molybdenum (Tradefos BMo Tradebor Mo) gave the same growth (15.4%), but at different stages of development of winter peas: Tradefos BMo, which, apart from trace elements, contains soluble forms of phosphorus and potassium, provided such an increase when fertilising at the stage of spring vegetation renewal, while Tradebor Mo – when fertilising vegetative plants twice (VSR+budding)

In the dry conditions of 2022, there was no significant effect of treating crops with a solution of organic amino acids (Delfan plus) during vegetation recovery, while the use of an algae-based preparation (Phylgreen BMo) in these weather conditions did not generally result in a significant increase in pea yields. In the more favourable year of 2023, the increase from spraying with Phylgreen BMo solution was 0.53-0.69 t/ha ($LSD_{0.95}$ = 0.15 t/ha) or 23.3-30.4%; on average, over three years, the maximum effect was obtained when using this preparation in the budding phase and when double spraying (VSR+budding), when the increase in winter pea yield was 15.6% and 13.8% or 0.34 t/ha and 0.30 t/ha.

In 2023, Tradefos BMo and Tradebor Mo organo-mineral fertilisers provided the maximum growth (18.1% and 15.0%) when used during the budding phase. On average, over three years, Tradefos BMo provided the maximum increase in pea yields when treating crops in the budding phase (14.2%), while Tradebor Mo when used at the time of pea vegetation recovery – 11.8%, and 13.8% when applied twice. Thus, there is instability in the effectiveness of the LOMF in time and space. However, based on the findings of three years of research (Fig. 3), it is possible to determine the best time for treating winter pea crops with LOMF solutions.

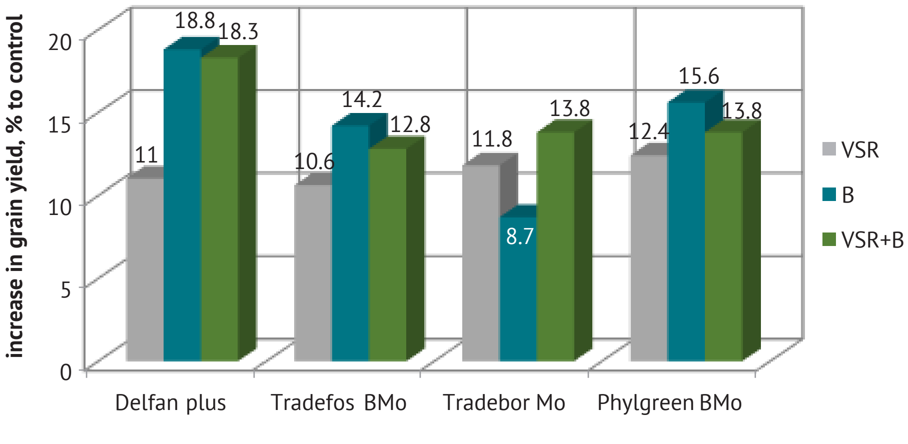

***Figure 3.** Average yield increases of winter peas using LOMF over the years of research*
Source: *compiled by the authors of this study based on conducted research*

All the studied LOMFs (except Tradebor Mo) contributed to the maximum increase in the yield of peas of winter sowing when used in the budding phase, the increase ranged within 14.2-18.8%. Delfan plus (+18.8%) stands out among the preparations in terms of effectiveness. According to the level of impact on yield, the LOMFs are ranked as follows: Delfan plus > Phylgreen BMo > Tradefos BMo > Tradebor Mo. The findings obtained are confirmed in the studies of other researchers. Many studies report an increase in the yield of various crops by 10-25% under the influence of preparations containing trace elements. For instance, in the experiments of M.V. Kapinos (2020), conducted in the Southern Steppe of Ukraine, the increase in the yield of three pea varieties with pre-sowing seed treatment with such preparations ranged within 14.9-15.2%.

According to the conclusions of S. Skok *et al.* (2023), the effectiveness of the use of micronutrient preparations depends on the crop, its developmental stage, and the frequency of treatment: when peas, winter wheat, sunflower were treated twice with Nano-Agro solution in the early stages of development (before flowering), yield increases ranged within 12.0-16.0%, and a single treatment after flowering was 4.0%. According to the findings of M. Janmohammadi *et al.* (2023), obtained in the arid conditions of northwestern Iran, the introduction of trace elements by foliar spraying of wheat crops increased the yield within 10-14%, and in combination with pre-sowing seed treatment and the use of biological products – up to 21.0%. However, the researchers do not analyse the stability of such factors depending on weather conditions, elements of technology, and the level of soil fertility.

Quality of winter pea grain. The main quality indicators of commercial peas are grain protein content and grain size (thousand-kernel weight). Within each year of research, the protein content in pea grain of the experimental variants substantially exceeded that of the control (Table 3).

***Table 3**. Protein content in winter pea grain and its yield from 1 ha of sowing by experimental variants*

Experiment variant	Processing phase	Protein, %			Protein, kg/ha				
		2021	2022	2023	2021	2022	2023	mean	± to control
control	–	18.63	21.76	20.85	568.2	267.2	473.2	436.2	–
Delfan plus	SVR	19.48	23.48	22.53	662.3	288.2	594.9	515.1	78.9
	B	20.12	22.71	22.75	712.1	303.1	664.1	559.8	123.6
	SVR+B	20.20	22.69	22.80	743.4	312.0	615.6	557.0	120.8
Tradefos BMo	SVR	19.23	23.05	23.15	623.0	327.0	597.2	515.7	79.5
	B	19.52	22.91	22.97	683.2	300.5	615.6	533.1	96.9
	SVR+B	20.07	23.39	23.18	722.5	315.7	581.8	540.0	103.8
Tradebor Mo	SVR	19.28	22.61	22.56	717.2	296.8	548.1	520.7	84.5
	B	19.89	23.58	23.07	642.4	302.1	602.0	515.5	79.3
	SVR+B	20.01	22.48	23.27	706.4	318.6	577.1	534.0	97.8
Phylgreen BMo	SVR	19.25	22.52	21.42	631.4	277.7	608.3	505.8	69.6
	B	19.86	22.68	22.00	665.3	280.9	651.1	532.4	96.2
	SVR+B	20.15	22.03	22.70	681.1	277.8	635.6	531.5	95.3
LSD_{095}		0.56	0.60	0.75	–	–	–	–	–

Notes: ** – spring vegetation recovery; ** – budding; *** – spring vegetation recovery + budding*
Source: *compiled by the authors of this study based on conducted research*

Under the conditions of drought in 2022, there was no significant dependence of pea protein content on the term and frequency of treatment, but under conditions of relatively better moisture availability (2021 and 2023), a significant increase in protein content was observed when fertilising crops during the budding phase and at two times. On average, over three years, the maximum increase in grain protein content relative to the control variant was observed when using Tradebor Mo in the budding phase (8.7%) and Tradefos BMo (+8.8%) with two fertilisations (Fig. 4); the minimum increase compared to other preparations was observed in the Phylgreen BMo variants: from 3.2% to 6.0%.

The protein yield per unit area was determined by the yield and concentration of the product in the grain, and its value in the experimental plots significantly exceeded the control both for each of the years of research and on average (Table 3, Fig. 5).

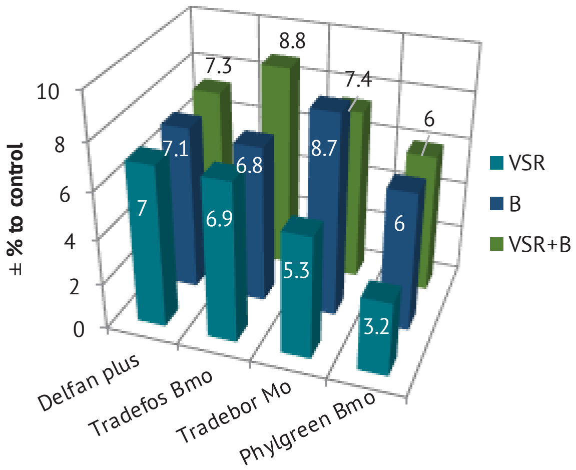

***Figure 4**. Increase in protein concentration in winter pea grain relative to control*
Source: *compiled by the authors of this study based on conducted research*

Figure 5. *Increase in protein yield per unit area of winter sown peas relative to the control*
Source: *compiled by the authors of this study based on conducted research*

Notably, the percentage of increase in protein yield when feeding during the budding phase and under conditions of double spraying have very close values within one preparation in three cases out of four: Delfan plus – 27.7-28.3%; Tradefos BMo – 22.3-23.8%; Phylgreen BMo – 22.1-21.8%. Double feeding of winter pea crops with Tradebor Mo solution leads to an increase in protein yield by 22.4%, while with single treatments – 19.4-18.2%. The effect of organo-mineral preparations on the thousand-kernel weight of pea grains is positive: in all years and in all variants there is a tendency to improve the size (Table 4).

Table 4. *Thousand-kernel weight of wintering peas by variants of LOMF fertilisation*

Experiment variant	Processing phase	Thousand-kernel weight, g				± to control
		2021	2022	2023	avg	gram
control	–	164.2	181.7	184.7	176.9	–
Delfan plus	SVR	183.4	182.1	185.6	183.7	6.8
	B	185.3	178.7	180.1	181.4	4.5
	SVR+B	186.3	185.8	186.1	186.1	9.2
Tradefos BMo	SVR	186.2	181.9	183.9	184.0	7.1
	B	176.9	181.5	184.0	180.8	3.9
	SVR+B	182.3	183.7	188.4	184.8	7.9
Tradebor Mo	SVR	178.6	184.1	186.2	183.0	6.1
	B	176.3	183.6	182.2	180.7	3.8
	SVR+B	180.4	183.0	184.0	182.5	5.6
Phylgreen BMo	SVR	172.2	180.4	184.3	179.0	2.1
	B	174.3	182.6	183.8	180.2	3.3
	SVR+B	175.2	180.4	187.0	180.9	4.0
LSD_{095}		7.9	3.8	4.2	–	

Notes: ** – spring vegetation recovery; ** – budding; *** – spring vegetation recovery + budding*
Source: *compiled by the authors of this study based on conducted research*

Only in 2021, the thousand-kernel weight was significantly higher (8.0-22.1 g) than the control variant at LSD_{095} = 7.9 grams. On average, over three years, the increase in the thousand-kernel weight did not exceed the level of 5% error (Fig. 6). However, polynomial trend lines (second degree) within each of the studied preparations showed a high probability of increasing the thousand-kernel weight when switching from a single feeding during the period of vegetation recovery to a double feeding (SVR+budding), as evidenced by the approximation coefficients at the level of 0.95-0.99. The results obtained suggest the significance of the frequency of fertilisation in the cultivation of winter peas, which was confirmed in the experiments of V.V. Shevchuk (2023) in the conditions of the Vinnytsia Oblast on two winter pea varieties NS Moroz and Enduro, where a combination of pre-sowing seed treatment with biological preparations, post-sowing application of $N_{45}P_{45}K_{45}$ and two-time foliar feeding with microfertilisers (3-5 leaves and budding) promoted growth plant mass, depending on the microfertiliser options, ranges within 15-66%, and when using one top dressing – within 12-46%.

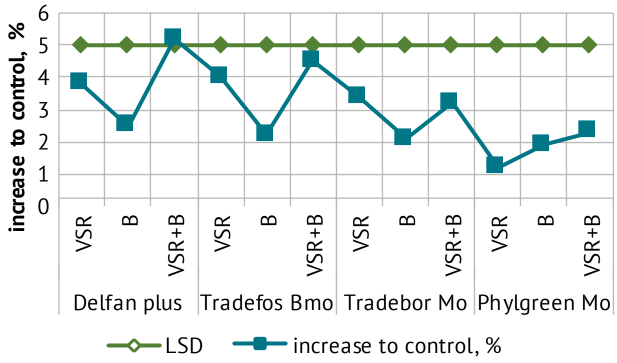

***Figure 6**. Increase in thousand-kernel weight compared to the control variant*
***Source:** compiled by the authors of this study based on conducted research*

Most of the observations on the impact of fertilisers on grain yield and quality were made in studies with spring peas and confirm the hypothesis that these indicators, even for a legume, depend on improved mineral nutrition, including nitrogen, and the degree of impact can be determined by the type of fertiliser, timing of application, and doses, but there is a positive effect in most cases. With equal doses of nitrogen from different sources: mineral fertilisers, cattle manure, and sheep manure (Karadaş & Ceyhan, 2023), the increase in the thousand-kernel weight of peas compared to the control without fertiliser was 13.4%, 5.5%, and 5.2%, while the protein concentration was 0.7%, 1.7%, and 2.9%, respectively.

L. Yeremko *et al.* (2024) noted the advantage of fractional application of nitrogen over one-time application and the combination of post-sowing application $N_{30}P_{45}K_{45}$ with feeding N_{15} in BBCH 22–23, which made it possible to increase thousand-kernel weight, yield, protein content, and total protein yield by 26.2%, 11.1%, and 43.5%, respectively, compared to the control. The use of chelated micronutrient fertilisers in combination with liquid biofertilisers increased the availability of nutrients and contributed to an increase in the thousand-kernel weight and protein content in pea grains (Sayed & Ouis, 2024), which is not in contradiction with the findings of the presented study. On the infertile sandy soils of Egypt, A.E.M. Eata *et al.* (2020) studied the effectiveness of foliar spraying with Agua Cool against the background of organic (compost at a rate of 2.5 t/ha) and mineral nitrogen (ammonium sulphate – 243 kg/ha); in the first case, the protein concentration in pea grain increased by an average of 8.2%, while the thousand-kernel weight – by 9.6% compared to the control without fertiliser, and against the background of mineral nitrogen – by 9.0% and 24.1%.

In the presented studies, the drug Delfan plus was used, which is a solution of L-£ amino acids obtained by acid hydrolysis of animal products. K. Dinkeloo *et al.* (2020) found that amino acids have an advantage over other nitrogen sources due to their mobility and easy transport in plants and therefore directly or indirectly affect plant growth, yield, and product quality. Admittedly, Delfan plus, when introduced into pea cultivation technology, increased grain yield from 11.1% to 18.8%, while protein content increased from 7.0% to 7.3% compared to the control (Fig. 4). The positive effect of the amino acid when using an acidic biostimulant identical in composition to Delfan plus was found in the experiments of W. Biel *et al.* (2023), where the yield of pea seeds increased by 13.0%, while the protein concentration in peas increased by 2.1 absolute percent or 9.4% relative to the control variant, which is also consistent with the data presented by Y. Mohammed *et al.* (2018) and S. Daba *et al.* (2022).

However, there are also results that point to the greater importance of factors other than fertilisers. Thus, in Poland, a long-term experiment using nitrogen isotopes (Faligowska *et al.*, 2022) showed that nitrogen accumulated in pea seeds from three sources: the atmosphere (average value 35.2%), fertilisers (6.8%), and soil (57.9%), which was 48.6%, 9.9%, and 85.4 kg/ha, respectively. On three pea varieties, D. Janusauskaite (2023) studied the effectiveness of nitrogen application in the norm from 0 to 60 kg/ha against the background of $P_{40}K_{80}$ and showed that the protein concentration in the grain had a greater influence on precipitation during the growing season (48.6-52.6%), while the combined effect of weather conditions and nitrogen fertilisers was within 1.1-2.2% of the total variance of protein content; therewith, the protein concentration in pea grains of fertiliser variants decreased by an average of 2.6% relative to the control without fertilisers, and increasing the dose of mineral nitrogen reliably reduced the thousand-kernel weight by 2.7-3.5%.

However, from the standpoint of scientific development, both positive and negative and complex results do not contradict each other but complement and expand knowledge and contribute to the development of more sound elements of crop cultivation technology, considering climate change, varietal characteristics, soil condition, and type.

CONCLUSIONS

Liquid organo-mineral fertilisers: Delfan plus, Phylgreen BMo, Tradefos BMo, Tradebor Mo show effectiveness on pea crops sown in winter, but it is not stable in terms of the impact on yields and depends on weather conditions and the type of preparation: yield increases over the years of research ranged within 0-30.4%. The level of winter pea grain yield was greatly influenced by precipitation during the growing season: paired correlation coefficients showed a very high dependence on the amount of precipitation during the entire period of plant growth and development (r = 0.94), a high dependence on moisture accumulation at the time of spring vegetation resumption (r = 0.89), and an average dependence on the amount of precipitation during the pre-germination and active spring vegetation period (r = 0.62-0.66), and the share of precipitation influence from the cessation to the resumption of vegetation was 51.3%. For each 1 mm decrease in precipitation, the yield decreased by an average of 14.6 kg/ha over the growing season. Precipitation during the grain ripening period had a weak negative effect on grain yield (r = -0.40). The increase in temperature during the entire period from the resumption of spring vegetation negatively affected the level of productivity (r = /-0.54/–/-0.89/), the greatest impact on the value of productivity was made by the average monthly temperatures of April (r = -0.79) and June (r = -0.89).

Based on three years of research, the following can be distinguished: Tradefos BMo (4 l/ha) and Phylgreen BMo (2.0 l/ha) are best used in the budding phase of winter peas, which ensures an increase in yield by 13.1% and 15.6%, and Tradebor Mo (2.5 l/ha) – during the spring vegetation recovery period (+11.8%), if a second treatment is carried out during budding, the yield increase will be 12.4%. All the tested preparations had a significant effect on both the absolute protein content of pea grain and its yield per sown area, with the latter increasing within 14.1-30.6%. The effect of liquid organo-mineral fertilisers on the thousand-kernel weight was positive but fluctuated mostly within the limits of reliability.

Calculations based on the results of research with liquid organo-mineral fertilisers enriched with trace elements boron and molybdenum and organic amino acids showed that fertilising pea crops for winter sowing with their solutions makes it possible to obtain additional profit in the amount of 1.52-2.81 g for each UAH spent (in conditions of severe drought – 0.35 UAH/kg). These findings were obtained at a high level of availability of available forms of nitrogen and phosphorus in southern black soil and a prominent level of potassium. Winter sowing of peas is considered a promising technique in the context of climate change in the Southern Steppe, and therefore it is worth investigating the effectiveness of liquid organic-mineral fertilisers depending on the level of soil fertility and their use in combination with other elements of technology, such as sowing dates and pre-sowing seed treatment.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Рідкі органо-мінеральні добрива в технології вирощування гороху зимуючого

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Анотація. Питання пристосування до кліматичних змін через розширення видів сільськогосподарських культур викликало інтерес до гороху зимуючого, введення якого в сівозміни дасть можливість стабілізувати врожайність зернобобової культури, позитивно вплинути на родючість ґрунту та підвищити продуктивність ріллі, але система живлення гороху підзимової сівби потребує вивчення та оптимізації, особливо з огляду на тенденції зростання вартості мінеральних добрив. Метою представлених матеріалів було дослідження впливу рідких органо-мінеральних добрив на врожай та якість зерна гороху підзимової сівби. Для реалізації поставлених завдань був виконаний польовий дослід в умовах Одеської області у період 2021-2023 рр. Повторність в досліді чотирьох кратна, розташування варіантів – систематичне. В досліді використано рідкі органо-мінеральні добрива, які вносили одноразово при відновленні весняної вегетації, у фазу бутонізації та двічі (відновлення весняної вегетації+бутонізація); контрольний варіант не передбачав внесення препаратів. Встановлено, що застосування рідких органо-мінеральних добрив на посівах гороху зимуючого сприяє підвищенню його врожайності, але величина зростання не стабільна, залежить від погодних умов і за роками досліджень коливалася від 0 % до 30,4 %. Досліджувані удобрювальні речовини мали суттєвий вплив на концентрацію білка в зерні гороху, вихід якого з одиниці площі зростав в середньому на 22,4 %, маса 1000 насінин збільшувалася, але в межах достовірності. Отримані результати вказували на можливість використання рідких органо-мінеральних добрив при вирощуванні гороху зимуючого за ресурсоощадною чи органічною технологією в зоні високого ступеня метеорологічних ризиків, але слід враховувати, що їх ефективність визначається складом иа кратністю внесення. Практична цінність дослідження полягає у розробленні елементів системи живлення, яка забезпечує підвищення врожайності гороху підзимової сівби на 0,24-0,41 т/га високий вміст білка і рівень рентабельності його виробництва – 117-152 %, а використання рідких органо-мінеральних добрив сприяють біологізації технології вирощування гороху, скороченню витрат на мінеральні добрива да зниженню хімічного навантаження на ґрунти

Ключові слова: зернобобова культура; погодні умови; удобрювальні речовини; продуктивність; якість зерна