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Effect of organic products on productivity, stability and feeding value of *Pisum sativum* L.

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Abstract

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In the near future, organic products such as fertilizers and nanoproducts are anticipated to play a pivotal role in modern agriculture, contributing to the development of ecologically and sustainably oriented farming practices. The objective of this study is to investigate the individual and combined use of organic products: Litovit and Nagro (foliar nanofertilizers) and Madex and Agrikol (bioinsecticides), on the productivity, stability, and nutritional value of field peas. The experimental controls are untreated control, and standard grown peas using synthetic products (foliar fertilizer Crystalon and insecticide Proteus110OD).

Results indicate treatment with organic nanofertilizers Litovit and Nagro, either individually or in combination with bioinsecticides Madex and Agrikol, invoke a positive effect on the dry biomass productivity of field peas, resulting in yield increase ranging from 9.7% to 35.6% compared to the untreated control. When applied individually, Litovit achieves higher yield compared to the synthetic fertilizer Crystalon, while Nagro shows statistically inconclusive results. The combination Litovit + Madex demonstrates the highest and proven productivity (5407.72 kg/ha) compared to the synthetic combination (Crystalon + ProteusOD110). The synergistic effects of subadditive nature are most pronounced in combinations involving Litovit. Among the organic variants, the combination Nagro + Agrikol exhibits high stability based on a comprehensive evaluation using the methods of Eberhart, Russel, Tai, and Kang. All organic products lead to incread protein and decreased fiber content in the biomass. The forage plants with the highest dry matter digestibility were obtained after treatment with Nagro (73.25%), Litovit + Agrikol (73.05%), and Litovit (72.01%).

Keywords: Pisum staivum; organic products; dry mass productivity; stability; feeding value

Introduction

Pisum sativum L. is a valuable source of protein which contributes to maintaining crop biodiversity in a sustainable agricultural system (Klimek-Kopyra et al., 2023). According to Neugschwandtner et al. (2020) and Shanthakumar et al. (2022), it holds global importance as it is used for food, fodder, and industrial purposes. Based on FAO statistics, its cultivation area in 2022 was approximately 10 million hectares, yielding an estimated production of 33 million tons. In the moderate climate conditions field pea is an indispensable species suitable for both organic and sustainable agriculture thanks to its high productive potential and adaptability (Corre-Hellou & Crozat, 2005).

Organic agriculture is an ecological farming system that produces food based on the ecological balance of ecosystems, preventing soil fertility decline and pest issues. It represents a proactive approach, serving as an alternative to intensive farming, with the goal of reducing its negative impacts and contributing to the preservation of soil health and the biodiversity enhancement (Costa et al., 2023). The main criticisms of organic farming are associated with lower productivity and nutritional value, yield instability, and poor efficiency of the products used.

Meta analysis of over 1000 organic farmers, encompassing more than 1.9 million acres of organic farmland, revealed that on average, the organic yield amounted to 80% of the conventional yield (Kniss et al., 2016). Today, an increasing number of studies are not only focused on applying the principles of organic production but also on seeking opportunities to overcome these limitations (Kristensen Thorup et al., 2012).

In this context, the study and implementation of new plant-based products, nanoproducts, and the combined application of products with different biological actions serve as an alternative of overcoming the weaknesses of organic production (Georgieva et al., 2015; Perveen & Mushtaq, 2019). The aim of the current study was to investigate the effect of organic products on the productivity, stability, and nutritional value of field peas (*Pisum sativum* L.).

Materials and Methods

The experiment took place in the years 2015-2017 at the Institute of Forage Crops (Pleven). The predecessor was spring oats. The sowing of spring peas (variety Pleven 4) was conducted at a rate of 120 seeds/m^2. Following the requirements of organic production, the field experiment was implemented on an area where a monitored 2-year conversion period was accomplished. Eight variants of organic production with separate and combined applications of organic products were investigated – foliar fertilizers and bioinsecticides. Insecticide treatment is a mandatory technological element in pea cultivation due to the high population density of *Bruchus pisorum* in Pleven region. Nanoproducts (Litovit, Nagro) containing a complex of nutrients were used as foliar fertilizers of organic origin (Table 1). The utilized biological insecticides (Madex, Agricol) are based on granuloviral virus and natural polysaccharides. The experiment had two control variants:1) untreated control and 2) conventionally cultivated variants grown using synthetic-based products (foliar fertilizer Crystalon and insecticide Proteus 110 OD), cultivated on an area for conventional farming.

The two-factor field experiment was carried out using a randomized block method: Factor A – years, with three levels each (a1 – 2015; a2 – 2016; a3 – 2017) and Factor B – products and combinations of products, with 12 levels (b1 untreated control; b2 Litovit 2000 g/ha; b3 Nagro 500 ml/ha; b4 Madex 600 ml/ha; b5 Agricol 1000 ml/ha; b6 Litovit 2000 g/ha + Madex 600 ml/ha; b7 Litovit 2000 g/ha + Agricol 1000 ml/ha; b8 Nagro 600 ml/ha + Madex 600 ml/ha; b9 Nagro 600 ml/ha + Agricol 1000 ml/ha; b10 Crystalon 2000 g/ha; b11 Proteus 600 ml/ha; b12 Crystalon 2000 g/ha + Proteus 600 ml/ha). The size of the experimental plot was 10 m2, with three replications of each variant. All products were applied twice, during the budding and flowering phases. Harvesting of the aboveground biomass was performed during BBCH 74-75 phase (Meier, 2001).

The acquired data underwent a two-factor variance analysis to evaluate the influence of environment (years), products, and their interaction. The following parameters of yield stability were calculated: coefficient of ecological stability (regression coefficient) bi and variance of deviations from regression (Si^2; Eberhart & Russel, 1966); stability parameters ai and λi (Tai, 1979) and Kang's rank-sum (Kang, 1988).

Total biochemical composition of the forage (BBCH 74-

Table 1. Characteristic of used products

Products	Composition	Producer
Organic production		
Litovit	79.19% $CaCO_3$, 4.62% $MgCO_3$, 1.31% Fe, 0.33% N, 0.01% P, 0.005% Zn, 0.014% Mn, 0.002% Cu, 11.41% SiO_2	ZeoVITA, Germany
Nagro	humic acids – 5.6 g/l; fulvic acids – 2.07 g/l; N – 0.28 g/l; P – 0.226 g/l; K – 3.073 g/l; trace elements (Mg, Co, Mn, Zn, Fe, Cu, Mo, B, Ca, Se) – 1900 mg/l	BioPlant, Russia
Madex	2% granular virus with a titer of 6x10 granules + microparticles from the larvae of the apple fruitworm and water	Andermatt-Biocontrol, Switzerland
Agricoll	polysaccharide of plant origin	Biopol Natural, Netherlands
Conventional production		
Kristalon	N – 18% (ammonium nitrogen – 3.3%; nitrate nitrogen – 4.9%; amide nitrogen – 9.8%) P /P_2O_5/ – 18%; K /K_2O/ – 18%; Mg /MgO/ – 3%; S /SO_3/ – 5% trace elements: B – 0.025%; Fe – 0.070%; Mn – 0.040%; Cu – 0.010%; Mo – 0.0004%; Zn – 0.025%	Nu3 BV, Holand
Proteus OD 110	thiacloprid 100 g/l; deltametrin 10 g/l	Bayer CropScience, Germany

75 phase) including crude protein (CP), crude fiber (CF), and ash (AOAC, 2010) was investigated. Fiber components within the cell walls were quantified as neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) via a systematic detergent analysis by Goering & Van Soest (1970). Polysaccharides such as hemicellulose and cellulose, integral to the fiber fraction of the cell walls, were determined empirically: Hemicellulose = NDF – ADF; Cellulose = ADF – ADL. The degree of lignification can be presented with the relationship between ADL and NDF (Degree of lignification = ADL/NDFx100). Enzymatic *in vitro* digestibility of dry matter (IVDMD, %) was studied via a two-stage pepsin-cellulase method of Aufrere (Todorov et al., 2010).

The experimental data were processed statistically using the computer software PBSTAT.

Results

The three-year experimental period was marked by various meteorological conditions. The vegetative period (March-May) of 2017 had the highest cumulative precipitation values (226 mm) and an average daily temperature of 13.2°C. The experimental years 2015 and 2016 exhibited significantly lower precipitation levels (on average by 27%) and daily temperatures of 12.6 and 13.4°C, respectively.

Biomass, as a productivity parameter, is a crucial quantitative characteristic for crops (Kryvobok, 2000). Treatment with fertilizer products Litovit and Nagro had a notably positive effect on the field peas biomass development, increasing the numbers by 22.8% and 21.0%, respectively (Figure 1). According to the manufacturers, both products not only contain macro/microelements that enhance plant nutrition but also possess adaptogenic properties with a different mechanism of action, resulting in increased plant resilience under adverse environmental conditions (high temperatures, moisture deficiency). Besides that, the protective effect of biological insecticides against pests also contributes to the production of a larger amount dry mass, even if the values are lower compared to the control variant (13.9% for Madex and 9.7% for Agricol). When comparing the effects of organic fertilizer products with that of the synthetic fertilizer Crystalon, it was evident that Litovit enhances fodder yield (statistically) to a greater extent than Crystalon, and the effect of Nagro is comparable to that of synthetic fertilizer.

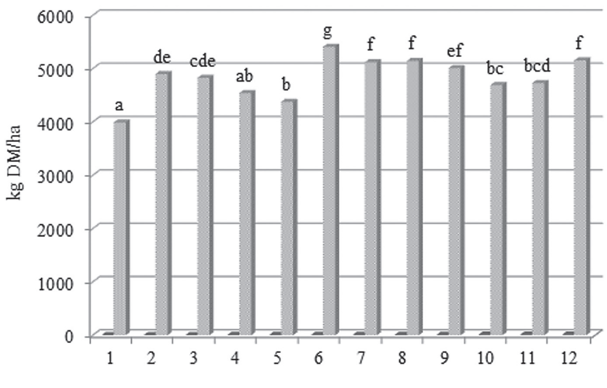

Fig. 1. Dry mass productivity under influence of organic and synthetic products

1. Control, 2. Litovit, 3. Nagro, 4. Madex, 5. Agricol 6. Litovit + Madex 7. Litovit + Agricol 8. Nagro + Madex 9. Nagro + Agricol 10. Crystalon 11. Proteus Od 110 12. Crystalon + Proteus Od 110

There were no statistically significant differences between the variants treated with Madex, Agricol, and Proteus OD 110. The combined application of either Litovit or Nagro with Madex or Agricol resulted in a significantly significant increase in yield (except for Nagro+Agricol) and demonstrates synergistic effects. Synergism is a process where certain elements or components perform better when used together (Markov, 1989). Synergistic effects were more distinct when mixing the organic fertilizer Litovit with bioinsecticides (on average, a 14.3% higher yield compared to its individual application) and to a lesser extent with combinations of Nagro (10.8%). A similar dependency was observed when the combination of synthetic products was applied, albeit with a slightly lower value of 9.5%. It is noteworthy that the synergistic effect in all combinations does not exceed the cumulative productivity of each individual product, meaning this is a sub additive synergism. The highest amount of biomass is generated by plants treated with Litovit in combination with Madex (5407.72 kg/ha), followed by the synthetic combination Crystalon with Proteus and all other organic combinations, with no statistically significant differences between them.

From the analysis of variance (Table 2) it is evident that experimental years exert a highly significant influence on the dry biomass yield, accounting for 94.5% of the total variation in the variants. This is attributed to the substantial differences in meteorological conditions across the three experimental years. The impact of the products is considerably lower (4.0%). There is a well-established interaction between the products and the reservoir mixtures with environmental conditions (A × B) – 0.7% at a probability level of $p \leq 0.1$. The low value indicates that the yearly conditions have a relatively low influence on their interaction concerning the yield.

The proven A × B interaction is a foundation for assessing the stability of each variant regarding the years (Table 3). In organic farming conditions, yield stability is as essential of a parameter as productivity. Based on regression coeffi-

Table 2. Analysis of variance for dry mass productivity

Source of variation	Degrees of freedom	Sum of squares	Influence of factor. %	Mean square	F-count	P-value
Factor A – years	2	355524512.8	94.5	177762256.4	1295.8**	0
Replication × Year	6	823121.6	0.2	137186.9	4.24**	0.0011
Factor B – products	11	15150543.6	4.0	1377322.1	12.20**	0
A × B	22	2482981.9	0.7	112862.8	3.49**	0
Error	66	2133505.8	0.6	32325.8	–	–
Corrected total	107	376114665.9	–	–	–	–

$^{*}p \leq 0.5$, $^{**}p \leq 0.1$, $^{***}p \leq 0.01$

cient *bi* and variance of SD regression values Si^2 it was found that the least stable combination was Litovit+Madex (bi = 1.11, Si^2 = 8862.84), as well as the insecticide Proteus OD 110 (bi = 1.14, Si^2 = 4004.35). The instability is mainly attributed to the significant differences in dry mass in these variants throughout individual experimental years as in those cases the meteorological conditions had the strongest influence. The best stability was registered by the organic variants Litovit and Nagro+Agricol, and the synthetic fertilizer Crystalon. In these three variants a linear type of stability is observed: proven bi values that are closest to 1. Considering the lower values of Si^2, Nagro + Agricol and Litovit receive a better evaluation as they are impacted less by the environmental conditions. The evaluation based on Tai method (1979) confirms the previously drawn conclusions, given the identical values of the parameter ai and the regression coefficient bi. The only observed differences were concerning the parameter λi, whose values indicated that the variance of deviation from regression is the weakest in the Nagro+Agricol and Litovit variants.

A crucial piece of information regarding the value of the variants is provided by Kang's rank-sum (KR) (Kang, 1988), which is based on the significant differences in yield and the variance of interaction with the environment. The importance of this criterion is that it provides a summarized assessment which ranks the variants by their economic value, that uses both non-parametric methods and statistical evidence of differences. Under organic production conditions, the most valuable options from technological point of view were the combination of Nagro + Agrico, as well as the individual application of Nagro. These variants exhibit both high yield and stability across different years. Satisfactory results were observed for Litovit (both individually applied, and in combination) and Nagro+Madex; variants that combine high grain yields with relatively good stability. The synthetic combination of Crystalon + Proteus OD 110 holds the best position according to Kang's rank-sum. The individual use of the insecticides Madex and Agricol, and the control, had low evaluation likely due to their low dry matter yield values.

The data presented in Table 4 demonstrate the primary biochemical composition, fiber content, and digestibility of field peas. The primal chemical composition has an uppermost importance in the assessment of the nutritional value and the efficient utilization of forages. The contents of CP, CF, and ash ranged from 13.64% to 18.56%, 20.24% to

Table 3. Stability paramethers of variants of organic and conventional fild pea production

Variants	bi	S_i^2	ai	**λi**	KR
Control	0.81**	320.37**	0.81**	965.36**	24
Litovit	1.03**	2982.81**	1.03**	6510.93**	11
Nagro	0.002**	8302.03**	0.002**	18268.27**	10
Madex	0.92**	1105.11**	0.92**	2544.31**	18
Agricol	0.89**	97.15**	0.89**	362.25**	21
Litovit+Madex	1.11**	8862.84**	1.11**	19498.79**	12
Litovit+Agricol	1.07**	699.81**	1.07**	1642.59**	11
Nagro+Madex	1.09**	3035.36**	1.09**	653.79**	12
Nagro+Agricol	1.03**	564.8**	1.03**	1243.12**	9
Kristalon	0.99**	4983.83**	0.99**	10967.22**	11
Proteus OD 110	1.14**	4004.35**	1.14**	8810.52**	9
Kristalon+Proteus OD 110	1.04**	3178.04**	1.04**	6497.01**	8

$^{**}p \leq 0.1$

23.23%, and 6.05% to 7.12%, respectively, with coefficients of variation (CV) of 8.7, 3.8, and 5.4%. Overall, all applied products had a positive effect on the protein content and negative effect on the fiber content of the biomass. After the organic product treatment, both separately and in combination, the CP content increased by 25.7% on average, while CF decreased by 8.0%. In contrast after application of synthetic products, the values were 12.7% and 7.7%, respectively. The combination of Nagro + Madex exhibited the highest CP (18.56%) and the lowest CF content (20.24%). It is important to note that the combined application of organic products increased the CP content to a greater extent (on average by 31.4% compared to the control) as opposed to individual application (on average by 20.0%).

The content of fiber components is also relevant for the quality and nutritional value of fodder (ten Brink et al., 2007). Adugna et al. (2012) pointed out that feed with high fiber and low protein content has low digestibility, limiting its free intake. In regard to the fiber components of cell walls, the coefficient of variation ranged from 2.1 to 4.7%. The variants with the lowest NDF values were Litovit (38.15%), Agricol (37.54%), and the combination of both (36.85%). Plants treated with Litovit and Litovit+Agricol, as well as those from the control variant, also exhibit low ADF (27.44–28.30%) and cellulose values (22.56–23.52%). Favorable hemicellulose content (above 10%) was observed in two variants only: control and Litovit, with an average value of 11.04% and a coefficient of variation of 18.1%. Besides the discussed dependances, the overall organic production was characterized by lower hemicellulose (7.89%) and higher cellulose content (25.35%) compared to conventional production (9.64 and 24.25%, respectively). A similar trend was observed regarding the degree of lignification. Data of dry matter digestibility was in the range from 66.58 to 73.25%. The top three positions were occupied by organic variants (Nagro – 73.25%, Litovit + Agricol – 73.05%, Litovit – 72.01%), followed by the synthetic combination of Crystalon + Proteus OD 110 (71.72%).

Discussion

Contrary to the commonly used farmyard manure and humate fertilizers, in the current study the spotlight was on nanobiofertilizers, applied solely or in combination with bioinsecticides with plant or microbial origin. A positive effect on both quantitative and qualitative parameters has been observed in various crops – wheat (Mardalipour et al., 2014), maize (Farnia & Omidi, 2015), sorghum (Mir et al., 2015),

Table 4. Principal composition, fiber components content and digestibility of *Pisum sativum* under the influence of organic and synthetic products (%), BBCH 74-75 phase, on average

Variant	CP	CF	Ash	NDF	ADF	ADL	HC	Cellulose	DL	IVDMD
1	13.64	23.23	6.22	39.34	27.44	4.88	11.90	22.56	12.40	70.68
2	15.93	21.35	6.55	38.45	28.28	5.47	10.17	22.82	14.10	72.01
3	16.86	20.64	6.78	38.19	30.83	5.44	7.36	25.40	14.15	73.25
4	15.63	21.56	6.05	39.83	30.43	5.34	9.40	25.09	13.35	68.66
5	17.09	21.67	6.98	37.54	31.27	5.39	6.30	25.88	14.35	66.58
6	17.82	22.31	7.12	39.16	32.30	5.30	6.86	27.00	13.65	67.63
7	17.44	20.60	6.08	36.85	28.30	4.78	8.55	23.52	13.00	73.05
8	18.56	20.24	6.64	38.68	30.30	5.25	8.38	25.06	13.60	67.96
9	17.86	22.67	6.78	38.91	30.51	5.01	8.40	25.50	12.85	67.36
10	15.18	21.08	6.46	38.81	29.00	5.06	9.81	23.95	12.75	68.61
11	15.35	21.66	6.13	39.47	29.67	5.06	9.60	24.61	12.70	68.86
12	15.58	21.56	6.48	38.64	29.19	5.01	9.52	24.18	12.95	71.72
Min	13.64	20.24	6.05	36.85	27.44	4.78	6.30	22.56	12.40	66.58
Max	18.56	23.23	7.12	39.83	32.30	5.47	11.90	27.00	14.35	73.25
Mean	16.41	21.59	6.52	38.64	29.79	5.16	8.85	24.63	13.3	69.70
SD	1.42	0.82	0.35	0.81	1.41	0.23	1.55	1.29	0.65	2.33
CV	8.7	3.8	5.4	2.1	4.7	4.4	18.1	5.2	4.9	3.3

1. Control, 2. Litovit, 3. Nagro, 4. Madex, 5. Agricol 6. Litovit + Madex 7. Litovit + Agricol 8. Nagro + Madex 9. Nagro + Agricol 10. Crystalon 11. Proteus Od 110 12. Crystalon + Proteus Od 110

CP – Crude protein; CF – Crude fiber; NDF – Neutral-detergent fiber; ADF – Acid-detergent fiber; ADL – Acid-detergent lignin; HC – Hemicellulose; DL – Degree of lignification; IVDMD – *In vitro* dry matter digestibility; The determination of pea feeding values was conducted by prof. Y.Naydenova legumes (Shukla et al., 2013), when either a single ganic/nanoproduct or a combination of products is applied. Under the conditions of the current experiment, the positive effect of organic product application, measured in relative values/units, was in the range of 9.7 to 35.6% in a matter of productivity. Naturally, the highest values were observed when the nanofertilizers Litovit and Nagro were utilized.

These variants demonstrate a high CP content (average 16.40%), low CF content (average 21.0%), and the highest content of digestible crude fiber (average 72.63%) – the main indicator related to feed digestibility. The mentioned values of digestible crude fiber and CP were higher compared to the synthetic fertilizer Crystalon (68.61 and 15.18%, respectively). Dry matter yield in Litovit exceeded the values of Crystalon by 4.4%, while the yield achieved by Nagro equals the one of Crystalon. The combined application of nanofertilizers and bioinsecticides provides an average yield of 5168.8 kg/ha, compared to 5154.64 and 3988.69 kg/ha for the synthetic mixture Crystalon + Proteus and the control, respectively. Interestingly, the organic combination provided increased CP content (average 17.92%) compared to the synthetic mixture Crystalon + Proteus (15.58%) and the control (13.64%). However, probably due to compensatory mechanism, the dry matter digestibility in this example (except for Nagro+Madex) was lower (67.65% compared to 71.72%). Undoubtedly, in the current study the high positive effect of applying organic products is due to the nanofertilizers. According to Kumar (2011), nanofertilizers are an alternative to conventional slow-release fertilizers, enabling efficient use of water and nutrients by plants.

Nanoparticles have unique physicochemical properties due to their large surface area, high reactivity, controllable pore size, and specific morphology (Siddiqui et al., 2015).

According to Kumar (2011), Raven (2003), and Abo-Sedera et al. (2016), the foliar fertilizers from Litovit range are the first of this type to increase the photosynthesis rate by releasing CO_2 inside the leaves. This way the plant metabolism is being activated while providing macro and micronutrients sufficient for the growth and development of healthy plants. The microparticles of Litovit allow easy absorption by the plant, and the content of Mg increases the overall chlorophyll content in the plant. The other micronutrients in the fertilizer (such as manganese, zinc, etc.) improve plant physiology by enhancing their resistance, growth, and crop yield. The release of carbon dioxide into plant tissues resulting from the breakdown of calcium carbonate enhances photosynthesis, elucidating the beneficial impact on vegetative growth.

Byan (2014) found out that the use of Litovit in *Phaseolus vulgaris* improves both the values of characters of green pods and vegetative growth compared to a control variant (distilled water). In another study of *Phaseolus vulgaris*, Abo-Sedera (2016) recommend mixed use of micronized calcium carbonate (Litovit) with mineral fertilizer or rabbit manure to enhance growth, chemical composition, productivity, and quality (increased protein content). Abd El-All (2019) investigated the application of different levels of Litovit (solely and combined with potassium fertilizer) in *Capsicum annuum* L. The results showed an increase in all vegetative characteristics, photosynthetic pigments, yield, and the content of protein, N, P, K, sugars, etc. A good effect is also observed in sugar beet after foliar treatment with marine calcite (containing calcium carbonate and silicon), leading to increased yield (up to 21%) and increased sugar content (Artyszak et al., 2014). For *Carum carvi* L. a mixture of natural nano-zeolite and biofertilizers provides good results in terms of growth and chemical composition compared to those obtained via synthetic products (Mahmoud et al., 2017).

Mahmoud & Taha (2018) noted that a mixture of nano Zn and Fe with chicken manure has a better influence on growth characteristics (leaves weight, seed oil yield) and chemical composition (macro and micronutrients, crude protein) in *Eruca sativa*, compared to commercial NPK fertilizer. This observation made the abovementioned researchers believe that in the near future nano and organic fertilizers will substitute chemical fertilizers as they enhance crop quality in addition to lowering the production costs and environmental pollution.

According to Agrobulros (2015) and Jakiene et al. (2015), the organic nanofertilizer Nagro contains substances from cold-molecularly synthesized cattle manure, biologically active substances, grained micro and macroelements, and beneficial soil microorganisms. Grinding was performed via nanotechnology aiming to obtain very small nutrient particles as the small size aids the penetration of the cell membrane, providing a better absorption.

In regard to the study of Pinchuk et al. (2019), the winter rye was found to increase its yield after treating the seeds with Nagro, with values ranging from 15–28% (for the Vlada variety) and 4–13% (for the Tetra variety). Similar results were observed after foliar treatment of wheat with Nagro (Ajdiev et al., 2017). Jakiene et al. (2015) compared the effects of 4 organic fertilizers (Azofit, Nagro, Bioplant Flora, and Raskila) on sugar beet. The highest yield and sugar content were obtained after foliar treatment with Nagro or Azofit at a dose of 1 l/ha. In addition to the favorable effects of using Nagro, Tedeeva et al. (2021) report improved symbiotic activity of chickpea and soybean after treatment with organic fertilizer.

The question regarding yield stability and the combination of fertilizers with plant protection products in organic farming conditions is under-examined. Most of the present literature is focused on conventional cultivation. For instance, Meena et al. (2015) observed synergistic effects when combined application of bioorganic combinations (NPK, Rhizobium, PSB /Phosphorus solubilizing bacteria/, and Vermicompost) in *Vigna radiata* (L.) Wilczek was conducted. The authors reported improved growth, yield (seeds and straw), and nutritional parameters (protein, nitrogen, phosphorus, and potassium). Atanasova & Maneva (2021) investigated the possibility of overcoming the phytotoxicity of certain herbicides after their joint application with Nagro in oats. They also observed an increase in productivity, especially by the combination Nagro + Derby Super. In a similar study, Delchev (2010) identified the presence of synergy from the combined use of organic foliar fertilizers (Lactofol, Terrasorb, Humustim) and herbicides (Lintur, Granstar, Derby) in durum wheat. In our previous study (Georgieva et al., 2015), the possibility of growing peas using organic products was explored: Biofa (foliar fertilizer), Polyversum (growth regulator), Nimazal T/C, and Pyrethrum FS-EC (bioinsecticides). The highest stability and yields were reported after two-fold treatment with the combinations Biofa + Pyrethrum and Polyversum + Pyrethrum (22.0 and 21.8% more than the untreated control).

The combined use of products exhibiting different biological actions (foliar fertilizers, growth regulators, stimulants, and plant protection agents) enhances their effectiveness and has a high economic impact by saving time, energy, and costs (Petroff, 2008).

In conclusion, according to Thirugnanasambandan (2018), soon the organic fertilizers, nanofertilizers, and nanopesticides are going to play a fundamental role in contemporary agriculture. They contribute to higher crop productivity, environmental friendliness, and low production costs, thereby contributing to the development of ecological and sustainable agriculture.

Conclusion

The use of organic nanofertilizers Litovit and Nagro, both independently and in combination with bioinsecticides Madex and Agricol, has a positive effect on the dry matter productivity of field peas. The yield increment ranges from 9.7 to 35.6% compared to the untreated control. When applied independently, the biofertilizers achieve higher (Litovit) or statistically inconclusive (Nagro) yields compared to synthetic fertilizer (Crystalon). The combination of Litovit + Madex stands out with the highest and proven productivity (5407.72 kg/ha) compared to a synthetic combination (Crystalon fertilizer + insecticide Proteus OD 110).

Combined application of the products results in manifestations of subadditive type synergism, which is the most strongly expressed in combinations involving Litovit.

Among the organic variants, the combination Nagro+Agricol exhibits high stability according to the comprehensive assessment by the methods of Eberhart & Russel (1966), Tai (1979), and Kang (1988).

Application of all organic products lead to an increase in protein content and a decrease in fiber content of field pea biomass. The fodder obtained after treatment with Nagro, Litovit+Agricol, and Litovit exhibits the highest dry matter digestibility (73.25%, 73.05%, and 72.01%, respectively).

Conflict of interest

The authors declare no conflict of interest.

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