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EFFECT OF MYCORRHIZAL FORMULATION MYCOFRIEND ON POTATO PRODUCTIVITY

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The **purpose** was to investigate the effect of mycorrhizal formulation Mycofriend on biometric parameters, productivity and biochemical composition of potatoes, as well as to determine the economic effect of its use**. Methods.** Field, laboratory, statistical. The study was conducted at the Institute of Vegetable and Melons Growing of NAAS. **Results**. The results on the effect of different doses of mycorrhizal formulation Mycofriend (complex of mycorrhizal fungi: *Glomus VS, Trichoderma harzianum;* microorganisms supporting the formation of mycorrhiza and rhizosphere of plants: *Streptomyces sp*., *Pseudomonas fluorescens*; phosphate-mobilizing bacteria: *Bacillius megaterium var. phosphaticum, Bacillus subtilis, Bacillus mucilogino-sus, Enterobacter* sp) on biometric parameters, yield and its constituents and biochemical composition of tubers are presented. Mycofriend clearly tend to increase the potato yield. On average, it was higher than the control (33.6 t/ha) by 4.6 t/ha and 4.4 t/ha at Mycofriend concentrations of 1.0 L/t and 2.0 L/t, respectively. Mycofriend also increased biometric parameters in comparison with the control (without treatment). In particular, the plant height after treatment of tubers with 1.0 L/t and 2.0 L/t increased by 0.19 m and 0.26 m, respectively; at the same time, the plant weight was also increased by 278 g and 590 g, respectively. There were upward trends in the contents of starch (by 1.29–3.03%) and ascorbic acid (by 4.08–5.94 mg/100 g) in tubers. Additional costs in the experiments ranged UAH 5935 to UAH 18,67 1/ha. However, a reduction in the prime costs by 0.17–0.33 UAH/kg was achieved, leading to a corresponding increase in the profitability of cultivation by 8.8–12.8 %. The most economically justified dose of the formulation was 1.0 L/t. **Conclusions.** It is possible to treat potato tubers with mycorrhizal formulation Mycofriend at a dose of 1.0 L/t and 2.0 L/t during pre-planting preparation, which significantly improves biometric parameters (plant height and vegetative weight). The highest gain in the yield was noted with 1.0 L/ha of Mycofriend – 4.6 t/ha. Here, the most significant decrease in the prime costs and increase in the profitability were observed.

***Keywords**:* mycorrhiza, potato, yield, biometric parameters, biochemical parameters, economic efficiency.

Introduction. In view of the climatic changes observed in the territory of Ukraine, there is a need to switch to new, more adapted, economically justified and economical technologies in order to adapt plants to stressful weather conditions. This will allow increasing the productivity of agricultural crops, preserve and improve natural resources, ensure the preservation of soil fertility and effective use of nutrients (*Didenko & Konovalova*, 2019).

Since it is impossible to avoid extreme meteorological factors when growing potatoes in Ukraine, the search for ways to minimize their negative impact on plants is gaining relevance (*Holovatiuk et al.,* 2021). New high-yielding varieties and high-quality planting material can ensure the maximum performance of plants if they are fully supplied with nutrients, timely cared and effectively protected against weeds, diseases and pests, optimal level of soil moisture is maintained during the growing period, and technological regulations are followed *(Bilinska et* al., 2021). However, due to the shortage of organic and mineral fertilizers and plant protectors, an effective way to solve the problem of increasing the potato yield is to apply biologicals, which help actively use soil nutrients and fertilizers, boost protective capacities of plants, their resistance to diseases, stresses, adverse weather conditions and have growth-stimulating and antimicrobial effects. This makes it possible to reduce the amount of pesticide load by 20–30% without reducing their protective effect (*Polishchuk et al*., 2013). Application of biologicals to restore soil fertility and to obtain high-quality plant products is a strategic trend in the modern agriculture development.

Among agricultural biologicals, microbial agents play an important role. These are ecologically safe agents with complex action, because microorganisms in their formulations not only fix nitrogen from the atmosphere or dissolve phosphates in the soil, but also produce amino acids as well as other compounds and substances with antipathogenic activities, restraining the development of phytopathogens, do not pollute the environment and are safe for animals and humans. In addition, enhancement of resistance of plants to adverse environmental factors (high and low temperatures, water deficit, phytotoxic pesticides) is an important aspect of the action of microbial agents. The harsher the soil, climatic and weather conditions are, the more important the role of biologization in crop cultivation technologies becomes. This explains the feasibility of using biologicals to improve plant nutrition and increase product quality (*Kovalenko et al.*, 2019).

Mialkovskyi and Bezvikonnyi (2022) reported that biologicals allowed increasing the assimilation surface of plants due to the stem number and height. In turn, this contributed to the formation of a larger vegetative mass and enlarged the assimilation surface. The plant performance rose due to application of biologicals, Kartoplex and Aminorost, because the number of marketable tubers increased. The yield increased by 4.2–5.1 t/ha, depending on varieties.

The drastic climate changes that we have observed in recent decades have a huge impact on agriculture. Currently, drought is one of the most influential factors limiting the productivity of agricultural crops. Water deficit in plants delays the growth of leaves and stems, and, in case of prolonged drought, the growth of roots, suppresses photosynthesis and respiration, accelerates leaf aging, results in retarded and underdeveloped generative organs, and finally leads to a significant drop in yield.

Experts think that it is possible to help plants cope with stresses by using mycorrhizal fungi-based biologicals. Mycorrhiza is a type of mutually beneficial symbiosis between plants and zygomycete fungi. During the formation of a mycorrhizal symbiosis, the fungus colonizes the root cortex tissues, establishing inner mycelium and modifying the cells contacting with the mycorrhiza. Having taken root on a plant, mycorrhizal fungi multiply on plant roots and spread into the surrounding soil as a large mass of absorbing threads, increasing the plant's absorption of water and nutrients. These threads are more than an order of magnitude thinner than root hairs and therefore are able to penetrate into the finest pores of soil minerals; there are such pores even in each sand grain. In 1 cm^3 of the soil surrounding the roots, the total length of mycorrhizal threads is from 20 to 40 meters. Mycorrhizal fungus increases the water absorption area by almost 100 times. It also increases the absorption of not only relatively immobile ions from the soil, i.e. phosphorus, potassium, calcium, magnesium, sulfur, zinc, copper, iron, but also enhances absorption and transport of much more mobile nitrogen ions, especially under arid conditions. Today, not only experimental, but also production indicators prove that agricultural crop cultivation using mycorrhizal formulations is several orders of magnitude more stable and effective in increasing yields while reducing production costs.

At the 7th International Conference on Mycorrhiza (*New Delhi*, 2013), the following results on yields that were increased due to mycorrhiza in different soils and in different climates were reported: soybeans yielded 15–40 % more, corn – 20–70 % more, spiked cereals – 15–30 % more, vegetables – 30–200 % more.

Review of Resent Studies and Publications. *Trichoderma spp*.-containing formulations were proven to positively affect morphological parameters of plants, such as root length, biomass, height, numbers of leaves, branches, fruits, etc. (*Halifu, Deng, Song, Song, 2019; Sajeesh*, 2015). *T. harzianum* significantly enlarges the cucumber root biomass (*Yedidia, Srivastva, Kapulnik, Chet*, 2001) and increases the number of lateral roots (*Contreras-Cornejo, Macías-Rodriguez, Cortes-Penagos, Lopez-Bucio,* 2009). *T. longipile* and *T. tomentosum* significantly increase the total leaf area of cabbage seedlings when they are grown in a greenhouse (*Rabeendran, Moot, Jones, Stewart*, 2000). *Trichoderma spp*. beneficially regulates physiological processes in plants, such as photosynthesis, gas exchange, absorption and assimilation of nutrients, water exchange, etc. The fungus improves the absorption of magnesium, a key component of chlorophyll (*Doni et al*., 2014). Harman et al. revealed that different strains of *Trichoderma* secreted acids such as coumaric, glucuronic and citric acids, which promote the release of phosphate ions that are unavailable to plants in most soils (*Zhao et* al., 2014). *T. harzianum* strain in the soil increased the availability of phosphorus, iron and zinc to plants. Enhanced growth of roots and shoots in response to *Trichoderma* inoculation boosted uptake of Cu, Na, Zn and other trace elements (*Li et al.*, 2015). Treatment with various Trichoderma species guaranteed high yields of agricultural crops such as mustard, wheat, corn, tomato, etc. (*Tucci et al., 2011; Haque, Ilias, Molla, 2012; El-Katatny, Idres, 2014; Naznin et al., 2015; Idowu , Olawole, Idumu, Salami, 2016*) and was a cheap, effective and environmentally safe method of biocontrol of phytopathogenic microflora in agrocenoses (*Sood et al., 2020*). Although *Trichoderma* is currently the most extensively studied fungal biocontrol agent, with some species already commercialized as biopesticides or biofertilizers, their widespread use is hindered by unpredictable field performance (*Alfiky, Weisskopf*, 2021). The stimulating effect of *Trichoderma* spp. was noted in many studies. Thus, positive effects of these fungal species on the growth of roots and above-ground mass of eggplant, pepper, and tomato were reported (*Rozenfeld*, *Vashchenko*, 2005). At the same time, some researchers (*Pidoplichko*, 1953) observed a phytotoxic effect and inhibition of the germination of coniferous seeds by fungi of the genus *Trichoderma,* which are noticeable for high enzymatic activity. Other scientists pointed to the fact that stimulatory and inhibitory effects depended on the fungus species of the genus *Trichoderma* (*Alvarez-García et al*., 2022).

Since potatoes yield in soil, effects of pre-planting treatment with mycorrhizal fungi consist not only in root formation, but also in stolon and tuber formation. Here, concentrations of beneficial microorganisms in soil affect both nutrient amounts and influx rates of nutrients reaching plants. Therefore, studies of effects of different doses of biologicals in pre-planting treatment of tubers on the potato performance features are relevant.

The **purpose** was to investigate the effect of mycorrhizal formulation Mycofriend on biometric parameters, productivity and biochemical composition of potatoes and to determine the economic effect of its application.

Materials and Methods. The study was conducted at the Institute of Vegetable and Melon Growing of NAAS in accordance with methods accepted in potato, vegetable and gourd growing in 2020–2022 (*Dospekhov, 1985; Bondarenko & Yakovenko, 2001; Kutsenko, Osypchuk & Podhaietskyi, 2002*). Field and laboratory experiments were carried out. Analysis of variance was used to test significance of the results.

The study design involved treatment of tubers of the Sifra potato variety by spraying with different concentrations of mycorrhizal formulation Mycofriend1-2 days prior to planting:

1. Control (no treatment)
2. Treatment of tubers with 0.3 L/t of Mycofriend.
3. Treatment of tubers with 1.0 L/t of Mycofriend.
4. Treatment of tubers with 2.0 L/t of Mycofriend.

Mycofriend is a complex of mycorrhizal fungi: *Glomus* VS and *Trichoderma harzianum*; microorganisms that support the formation of mycorrhizae and rhizosphere of plants: *Streptomyces* sp., *Pseudomonas fluorescens*; phosphate-mobilizing bacteria *Bacillius megaterium var. phosphaticum, Bacillus subtilis*, *Bacillus muciloginosus*, *Enterobacter* sp; and biologically active substances (phytohormones, vitamins, amino acids).

Potatoes were planted within the third 10 days of May in accordance with the 70x35 cm arrangement (plant density = 40,800 plants/ha); harvesting was completed within the third 10 days of August. The planting rate was 3 t/ha. The record plot was 25 m^2 in four replications. During the growing period, the biometric parameters were measured; the yield and its constituents were determined; tubers were biochemically analyzed; and the main economic indicators of the Mycofriend-containing technology of potato growing were calculated. Fertilizers were applied before planting at the dose of $N_{90}P_{90}K_{90}$. Drip irrigation was carried out; the lowest moisture content in the soil was maintained at 75–80 %.

Results. The meteorological conditions in the study years significantly influenced the growth and development of potato plants and caused fluctuations in the yields level of the studied varieties (Figs. 1 and 2). A significant increase in the maximum air temperature during the 2020 and 2021 growing periods was associated with high average daily temperatures in critical phases of the potato growth and development, which did not meet biological needs of the crop. Under these conditions, stolons and tubers developed mainly at night. To a large extent, this situation was caused by very little precipitation from mid-June to mid-August. This trend regarding weather changes has been observed in the study location for the last 20-25 years, confirming meteorological forecasts about climatic changes in the country and the world. However, the weather variability over the years is characteristic of the Eastern Forest-Steppe of Ukraine. Thus, in 2022, the average daily air temperature had a uniform profile and was lower than the long-term average. The average daily air temperature in the critical developmental phases of 17–21°C enabled vegetative mass to intensively grow, preventing the soil from overheating and favoring the development of underground parts of plants. The uniform distribution of precipitation in June, July and August helped maintain an optimal microclimate in the potato plantations. Due to sufficient moisture supply and moderate air temperature without extreme fluctuations, lots of tubers were formed, which meant a corresponding increase in the yield.

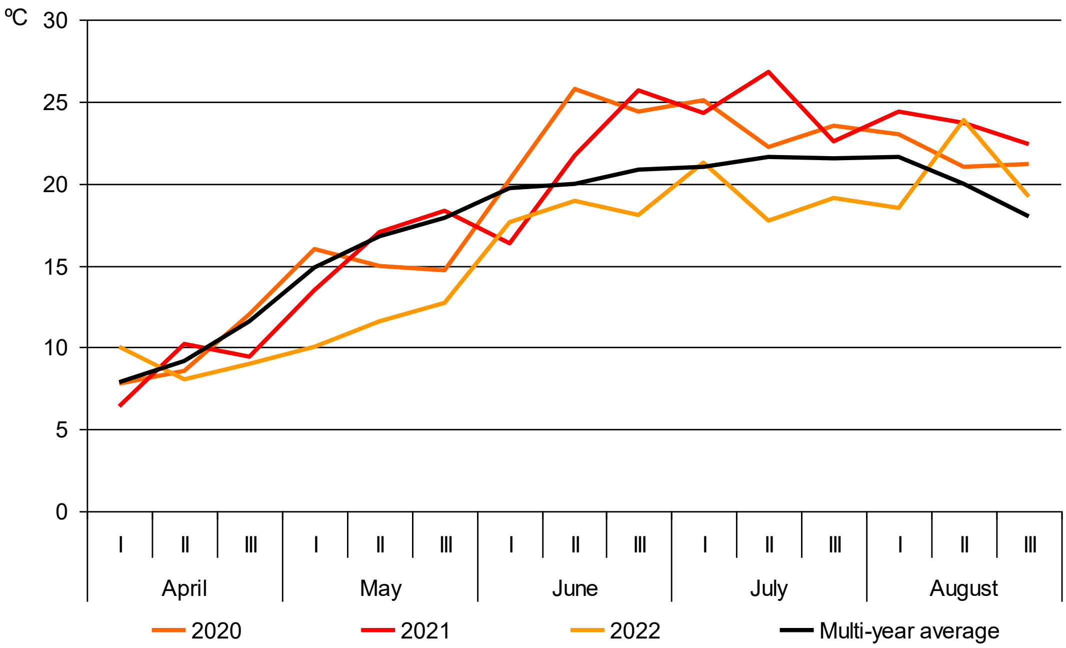

Figure 1. Average daily air temperatures during the 2020–2022 growing periods

During the 2020 growing period, 230.5 mm fell; in 2021–256.5 mm; and in 2022–344.4 mm (long-term average = 276.5 mm). Thus, in 2020–2022, we obtained data on the effectiveness of inoculation of tubers with Mycofriend under different growing conditions. Of particular interest are the results obtained in 2020 and 2021, when the weather was relatively unfavorable.

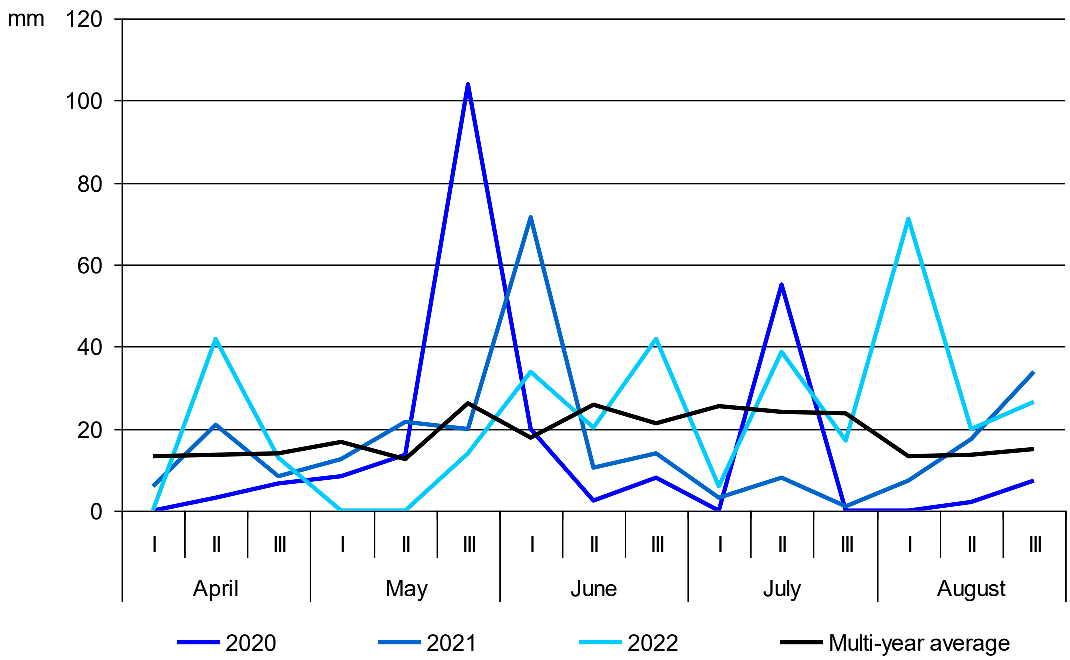

Figure 2. Rainfall dynamics during the 2020–2022 growing periods.

Rapidness of transition of potato plants to autotrophic nutrition and the bushing intensity are the main criteria for the effectiveness of preparation of tubers for planting. Depending on concentrations of beneficial microorganisms, temperature and water content in the root formation zone of the soil, plants change their intensity of absorption of nutrients and water. Increased doses of Mycofriend for pre-planting inoculation of tubers enhanced the growth of shoots and leaves. However, the mean height of plants was 0.72 m in 2020 and 0.70 m in 2021, while in 2022 it amounted to 0.82 m. The weather also affected the bush habitus and assimilation surface area. The mean weight of plants was 858 g in 2020 and 860 g in 2021, but in 2022 it increased to 1,300 g. At the same time, there was an upward trend in the biometric parameters of plants in the Mycofriend experiments (Table 1). With Mycofriend, plants were taller compared to the control by 0.16–0.26 m, depending on the formulation doses. The corresponding increase in the plant weight was 88-590 g. Analysis of the biometric parameters demonstrated that the largest vegetative mass of plants was achieved when Mycofriend was applied at a dose of 1.0 L/t or 2.0 L/t.

Table 1. Effect of Mycofriend on the biometric parameters of potatoes, 2020–2022

Dose, L/t	Plant height, m				Plant weight, g			
	2020	**2021**	**2022**	**Mean**	**2020**	**2021**	**2022**	**Mean**
No treatment (control)	0.59	0.55	0.64	0.59	688	692	920	767
0.3	0.70	0.68	0.87	0.75	640	646	1280	855
1.0	0.75	0.74	0.86	0.78	851	849	1436	1045
2.0	0.84	0.82	0.90	0.85	1251	1255	1564	1357
LSD_{05}	0,07	0.06	0.03		8.2	7.4	10.6	

Mycofriend-induced activation of growth processes not only promoted the development of the photosynthetic surface in plants, but also intensified the stolon and tuber formation. Regardless of the weather, the gain in the potato yields ranged 2.1 t/ha to 4.6 t/ha related to the control (33.6 t/ha) (Table 2). The most pronounced gain was achieved with 1.0 L/t and 2.0 L/t of Mycofriend.

Table 2. Effect of Mycofriend on the potato yield in 2020–2022

Dose, L/t	Yield, t/ha			
	2020	**2021**	**2022**	**Mean**
No treatment (control)	32.0	31.9	36.8	33,6
0.3	35.6	32.4	39.1	35,7
1.0	38.1	35.0	41.6	38,2
2.0	37.6	35.4	41.1	38,0
LSD_{05}	4,1	2.7	3.8	

The yield structure also changed under the influence of the formulation. Thus, the mean weight of tubers in the control was 60 g, and the number of tubers was 13.6/bush (Table 3). Treatment of tubers with Mycofriend at a dose of 2.0 L/t resulted in the maximum mean weight of tubers of 66 g, but not the greatest number of tubers (14.3/bush). The greatest number of tubers (14.6/bush) was obtained when Mycofriend was applied at a dose of 1.0 L/ha, which made it possible to obtain the greatest gain in the yield in this variant.

Table 3. Effect of Mycofriend on the potato yield structure in 2020–2022

Dose, L/t	Tuber number per bush				Mean weight of tubers, g			
	2020	**2021**	**2022**	**Mean**	**2020**	**2021**	**2022**	**Mean**
No treatment (control)	13.3	12.8	14.7	13.6	59	61	61	60
0.3	13.7	13.0	15.4	14.0	64	61	62	62
1.0	14.2	13.3	16.4	14.6	66	64	62	64
2.0	13.6	13.1	16.0	14.3	68	66	63	66
LSD_{05}	0.2	0.2	0.3		3.2	2.6	2.1	

Biochemical analyses showed that in the control the commercial product had the lowest amounts of starch (8.73%), ascorbic acid (10.9 mg/100 g) and nitrates (40.0 mg/kg) (Table 4). Treatment of tubers with Mycofriend at a dose of 1.0 L/ha produced yields with the highest amount of starch (11.76%) and the lowest amount of total sugars (0.86%). Increasing the dose of Mycofriend to 2.0 L/ha allowed increasing the dry matter content to 15.5% and the ascorbic acid content to 16.9 mg/100 g as well as accumulating the largest amount of nitrates (43.5 mg/kg), although this amount was not higher than the permissible level (250 mg/kg).

Table 4. Effect of Mycofriend on the biochemical composition of potato tubers, mean for 2020–2022

Dose, L/t	Dry matter, %	Starch, %	Total sugars, %	Ascorbic acid, mg/100 g	Nitrates, mg/kg
No treatment (control)	14.9	8.73	1.02	10.9	40.0
0.3	14.0	10.12	0.89	15.0	40.6
1.0	14.8	11.76	0.86	15.8	41.2
	15.5	10.43	0.89	16.9	43.5

Analysis of the main economic indicators of the Mycofriend-containing technology of potato growing indicated their improvement compared to the basic technology (Table 5). Additional costs in the experimental variants range UAH 5935 to UAH 18,671/ha. However, due to increased yields, the prime costs were reduced by 0.17–0.33 UAH/kg, meaning a corresponding increase in the profitability of cultivation by 8.8-12.8%.

Table 5. Economic indicators of the potato growing with Mycofriend application, mean for 2020-2022

Dose, L/t	Total costs, UAH/ha	Prime costs, UAH/kg	Profitability, %
No treatment (control)	194598	5.79	33.6
0.3	200533	5.62	42.4
1.0	208776	5.46	46.4
2.0	213269	5.61	42.5

1.0 L/t turned out to be the most economically justified dose of the formulation: its prime cost was UAH 5.46/kg (UAH 5.79/kg in the control) and the profitability was 46.4% (33.6% in the control).

Discussion. Mycorrhizal fungi are obligate symbionts that have a positive effect on the growth and development of host plants, increasing its provision with mineral nutrients resistance to adverse environmental conditions.

Mycorrhizae on potatoes enhances growth, boosts resistance to pathogens and increases yield. Colonization of roots with fungi increases the dry matter content both in vegetative mass and in roots, chlorophyll content and tuber yield. Such positive effects are attributed to increased rates of absorption of phosphorus, iron and magnesium by potato plants and to increased coefficients of utilization of phosphorus from the soil. In addition, fungus colonization reduces frequencies of some infections on potatoes or reduces the intensity of diseases. Some researchers noted that these fungi had a bioprotective function against the leaf pathogen *Phytophthora infestans*, as potato plants with mycorrhiza less suffered from disease as a result of the activation of systemic plant resistance to pathogens.

The obtained results confirm data on beneficial influence of useful microbiota on the the potato performance. This pattern was also observed in growing periods with adverse meteorological factors. The effectiveness of pre-planting treatment of potato tubers is confirmed by improved economic indicators of potato cultivation. The effectiveness of the investigated element of the technology has been confirmed by numerous studies, which demonstrated that this approach be an additional reserve for increasing the potato performance in the Ukrainian climate.

Conclusions. Mycorrhizal formulation Mycofriend can be used to treat potato tubers at a dose of 1.0 L/t and 2.0 L/t during pre-planting preparation, significantly improving the biometric parameters (plant height and vegetative mass). The highest gain (4.6 t/ha) in the yield was noted when tubers were treated with Mycofriend at a dose of 1.0 L/ha. Concurrently, the most significant decrease in the prime costs and increase in the profitability were recorded.

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ДІЯ МІКОРИЗОФОРМУЮЧОГО ПРЕПАРАТУ МІКОФРЕНД НА ПРОДУКТИВНІСТЬ КАРТОПЛІ

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Мета – дослідити дію мікоризоформуючого препарату Мікофренд на біометричні показники, продуктивність і біохімічний склад картоплі, а також визначити економічний ефект від його використання. **Методи.** Польовий, лабораторний, статистичний. Дослідження проводили в Інституті овочівництва і баштанництва НААН. **Результати**. Наведено результати впливу різних доз мікоризоформуючого препарату Мікофренд (комплекс мікоризоформуючих грибів: *Glomus VS, Trichoderma harzianum*; мікроорганізмів, що підтримують утворення мікоризи та ризосфери рослин: *Streptomyces sp., Pseudomonas Fluorescens*; фосфатмобілізуючі бактерії: *Bacillius Megaterium var. phosphaticum, Bacillus Subtilis, Bacillus Muciloginosus, Enterobacter sp*) на біометричні показники, врожайність, структуру врожаю та біохімічний склад бульб. Використання мікоризоформуючого препарату Мікофренд забезпечує чітку тенденцію до збільшення показників урожайності картоплі. В середньому вона була вищою ніж на контролі (33,6 т/га) на 4,6 і 4,4 т/га за концентрації препарату 1,0 та 2,0 л/т відповідно. Застосування мікоризоформуючого препарату дозволило збільшити також і біометричні показники у порівнянні з контролем (без обробки). Так, зокрема, висота рослин у варіанті з концентрацією препарату 1,0 л/т збільшилась на 0,19 м, а з концентрацією 2,0 л/т на 0,26 м; при цьому маса рослини також збільшилася відповідно на 278 г та 590 г. Також спостерігається тенденція до зростання вмісту крохмалю (на 1,29–3,03 %) та аскорбінової кислоти (на 4,08-5,94 мг/100 г) у бульбах. Додаткові витрати у варіантах досліду складають від 5935 до 18671 грн /га. Проте досягнуто зменшення собівартості продукції на 0,17-0,33 грн/кг, що призвело до відповідного зростання рентабельності вирощування на 8,8-12,8 %. Найбільш економічно обґрунтованою є доза препарату 1,0 л/т. **Висновки**. Використання для обробки бульб картоплі мікоризоформуючого препарату Мікофренд можна проводити з дозуванням 1,0 л/т та 2,0 л/т за передсадивної підготовки, що значно покращує біометричні показники (висоту рослин і масу вегетативної маси). Найвищій приріст врожайності був відмічений на варіанті з обробкою Мікофрендом у дозі 1,0 л/га – 4,6 т/га. При цьому спостерігається найбільш суттєве зменшення собівартості продукції та зростання рентабельності.

Ключові слова: мікориза, картопля, врожайність, біометричні показники, біохімічні показники, економічна ефективність.