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Features of the Pigment Complex of Winter Wheat Plants Depending on the Method of Fertilisation

Abstract. To maximise the yield of winter wheat, it is necessary to further optimise modern cultivation technologies to adapt them to changing environmental conditions. One of the aspects of plant adaptation to unfavourable abiotic factors is the active functioning of the photosynthetic apparatus, which depends on the number of nutrients applied. This paper investigates the effect of fertilisation on the state of the pigment complex of winter wheat plants in the Southern Steppe of Ukraine. Two varieties of winter wheat were selected for the study: Shestopalivka and Mason. The scheme of the experiment included the application of fertilisers during sowing (K_0; K_{12}) and foliar processing with various tank mixtures (urea; urea + magnesium sulphate; urea + magnesium sulphate + potassium monophosphate). The pigment content was determined by grinding fresh leaves of winter wheat with further addition of a solvent in the form of acetone. The pigments were measured using a spectrophotometer. The results of the studies showed that before foliar fertilisation, the content of chlorophyll *a* and carotenoids was higher in the leaves of plants of the Shestopalivka variety. At the same time, the content of chlorophyll b was higher for Mason plants by 17%, which may be a consequence of the adaptation of plants of this variety to a lack of light. A decrease in the pigment content in the leaves

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of plants of all experimental variants caused by the active growth of the photosynthesising surface and a decrease in the total dry matter mass was observed on day 3 after the foliar fertilisation. There was no significant difference between varieties in the content of photosynthetic pigments during this period. On the 10th day after foliar spraying, an increase in the content of chlorophyll a and b was observed for both studied varieties, which may be the result of the adaptation of the photosynthetic apparatus of winter wheat plants to lighting conditions. Foliar fertilisation of winter wheat plants with a tank mixture of urea with magnesium sulphate and potassium monophosphate contributed to a further increase in the content of chlorophyll a by 12-23% and chlorophyll b by 5-37%, depending on the variety compared to the control. The results of the conducted research indicate the high efficiency of the complex application of nitrogen-phosphorus-potassium fertilisers for foliar spraying of winter wheat plants at the stage of BBCH 31 both on the background of pre-sowing potassium fertilizers and without it

Keywords: *Triticum aestivum*, foliar fertilisation, chlorophylls a and b, carotenoids, LHC

RELEVANCE

Every year the technology of growing such an important food crop as winter wheat is further improved. However, there are still a number of factors that play an important role in shaping the quality and size of the future harvest. One of them is the rational application of mineral fertilisers, which, when optimally combined, increase the yield and improve the quality of winter wheat grain (Kalytka & Zolotukhyna, 2013).

An important component of the process of forming vegetative and generative organs of a crop is the photosynthetic activity of crops (Cherenkov *et al.*, 2015). Maintaining the active functioning of the photosynthetic apparatus of winter wheat leaves during the tube phase, which is the period of intensive plant growth and development and maximum absorption of moisture and nutrients, is one of the decisive factors in the formation of a high-quality crop yield (Gharanjik *et al.*, 2019). During this period, it is important to increase the supply of nitrogen to plants through foliar fertilisation, which is mainly carried out with fertilisers such as urea. This agronomic technique is widely used in farming, as this fertiliser is easily absorbed and combined with other foliar treatments (Sokolovska-Serhiienko *et al.*, 2016).

Another important factor contributing to high yields is the optimal supply of phosphorus and potassium nutrition. The application of potash fertilisers during sowing has a significant impact on plants during the growing season, which further affects the future harvest (Kudriavytska & Karabach, 2020). Meanwhile, there has been a growing interest in the foliar application of phosphorus-potassium fertilisers in the early tapering phase (Huliaieva *et al.*, 2015).

The active passage of photosynthesis serves to better supply nitrogen from the roots to the aboveground part of the plant. A photosynthetic apparatus is a volumetric reservoir for storing organic forms of nitrogen. That is why its efficiency determines the future yield potential of plants (Sheheda *et al.*, 2018), is the basis of their productivity, and largely depends on the content and ratio of pigments in plant

leaves. Chlorophylls *a* and *b* are indicators of the physiological state of plants, the functioning and activity of which are indicators of the potential ability of plants to form a crop. Another essential component of pigment systems is carotenoids, which are light-emitting pigments that protect chlorophyll from destruction during oxidative stress. The main functions performed by carotenoids are antioxidant, antennal, photoprotective, and structural.

The content of photosynthetic pigments (chlorophyll a and b and carotenoids) shows the physiological state of plants, their photosynthetic potential and the measurement of capacity, modelling, and prediction of the efficiency of the applied cultivation technology (Vagusevičienė *et al.*, 2012). The number of pigments in plants depends on a number of factors: genetic properties of the variety, stage of growth and development, environmental influences, and sowing density (Juchnevičienė & Vagusevičienė, 2015). The plant growing environment affects the mechanisms of pigment activity. Thus, fertiliser deficiency can lead to a decrease in pigment content in plant leaves (Smolikova & Medvedev, 2015). At the same time, improvements in the photosynthetic characteristics of the flag leaf, which is formed at the end of the tube exit phase, contribute to a high yield (Noor *et al.*, 2021)

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Feeding with nitrogen fertilisers during the phase of entering the tube significantly increases the content of chlorophyll a and b and carotenoids. Previously, it was established that the synthesis of chlorophyll depends on mineral nutrition. Such a measure affects the dynamics of leaf surface formation and the degree of leaf surface, which is reflected in the total leaf surface, photosynthetic potential and net photosynthetic productivity. The highest concentration of chlorophylls accumulates in the leaves shortly before flowering (Vagusevičienė *et al.*, 2012).

According to the results of research by Aistė Juchnevičienė and Ilona Vagusevičienė, it was found that fertilisation with nitrogen fertilisers stimulates the accumulation of photosynthetic pigments and prolongs the period of active photosynthesis. Chlorophyll is extremely sensitive to changes in the nitrogen content in the soil because most of the nitrogen is part of the pigments. A properly selected fertiliser system, including foliar fertilisation, delays the degradation of photosynthetic pigments and prolongs the period of active photosynthesis and ensures active transport of assimilates to the seeds, thereby determining the yield (Juchnevičienė & Vagusevičienė, 2015).

Foliar fertilisation is becoming a more common practice in agriculture to increase yields. It can effectively make up for nutrient deficiencies and can be used as the main method of providing plants with the necessary micronutrients (Jankowski *et al.*, 2016).

The results of research by I.B. Kovalyshyn and V.V. Shevchenko reveal that foliar treatment with phosphorus-containing fertilisers preserves the activity of the photosynthetic apparatus and slows down the ageing process during the reproductive development of winter wheat plants (Kovalyshyn & Shevchenko, 2020).

The purpose of the study is to determine the effect of the fertilisation method on the state of the pigment complex of winter wheat plants in the Southern Steppe of Ukraine.

MATERIALS AND METHODS

The study was conducted at leading enterprises in the Melitopol district of Zaporizhzhia oblast

in 2019-2021. Two varieties of winter wheat were used: Shestopalivka, the most common variety in the south-eastern region of Ukraine (Bilousova, 2018), classified as a physiologically dual-nature variety, and Mason, a Canadian transgenic winter wheat variety developed in 2016 using nanotechnology to transform wheat DNA cells. The two-factor experiment included determining the effect of pre-sowing potassium fertilisation (K_0; K_{12}) and foliar treatment of plants with different tank mixtures in the phase of the beginning of the tube emergence: urea (N (control)); urea + magnesium sulphate (N+Mg); urea + magnesium sulphate + potassium monophosphate (N+Mg+PK) on the content of the main photosynthetic pigments. The consumption rate of urea is 10 kg/ha, magnesium sulfate – 2 kg/ha, and potassium monophosphate – 1 kg/ha.

To determine the pigment content, fresh leaves of winter wheat were crushed with scissors and a 0.1-0.2 g sample was ground in a porcelain mortar with $CaCO_3$. 5 ml of acetone solvent was added and stirred. The resulting suspension was then filtered into a dry measuring cone through a filter. 10 ml of acetone was re-added to the mortar, rinsed and filtered. The filter was washed with acetone until the pigments were completely removed. The resulting extract was poured into a 50 ml flask and brought up to the mark with a solvent and stored in a dark place before determining the pigments. The pigment content was determined using a 2800 UV/VIS SPECTROPHOTOMETER at wavelengths of 440.5, 644, and 662 nm (Hrytsaienko et al, 2003). The obtained data were statistically analysed using Microsoft Excel.

RESULTS

The chlorophyll content of winter wheat leaves affects the process of solar energy absorption by plants. At the same time, carotenoids are important pigments that characterise the photosynthetic apparatus of plants and transfer the energy of the absorbed light quantum to chlorophyll for photochemical work and protect chloroplasts from photooxidation. As demonstrated by the results of the studies (Table 1), the analysed winter wheat varieties differed in pigment content and their ratio.

Table 1. The state of the pigment complex of winter wheat plants at stage BBSN 31 before foliar fertilisation, the average for 2020-2021

Cultivar (factor A)	Pre-sowing fertilisation (factor B)	Foliar fertilisation (factor C)	Pigment content, mg/g of dry matter			(chl.*a*)/(chl.*b*)	chl/car
			chlorophyll *a*	chlorophyll *b*	carotenoids		
Shestopalivka	K_0	N (k)	4.94 ± 0.76	1.46 ± 0.17	1.91 ± 0.30	3.38	3.35
		N ± Mg	4.92 ± 0.66	1.49 ± 0.30	1.88 ± 0.21	3.30	3.41
		N ± Mg ± PK	4.98 ± 0.50	1.52 ± 0.12	1.88 ± 0.26	3.28	3.46
	K_{12}	N (k)	4.20 ± 0.99	1.64 ± 0.40	1.74 ± 0.33	2.56	3.36
		N ± Mg	4.19 ± 0.94	1.64 ± 0.45	1.64 ± 0.24	2.55	3.55
		N ± Mg+PK	4.21 ± 0.95	1.69 ± 0.58	1.67 ± 0.33	2.49	3.53

Table 1, Continued

Cultivar (factor A)	Pre-sowing fertilisation (factor B)	Foliar fertilisation (factor C)	Pigment content, mg/g of dry matter			(chl.*a*)/ (chl.*b*)	chl/car
			chlorophyll *a*	chlorophyll *b*	carotenoids		
Mason	K_0	N (k)	4.22 ± 0.91	1.71 ± 0.46	1.61 ± 0.32	2.47	3.68
		N ± Mg	4.33 ± 0.89	1.78 ± 0.62	1.70 ± 0.37	2.43	3.59
		N ± Mg ± PK	4.28 ± 0.94	1.77 ± 0.32	1.69 ± 0.23	2.42	3.58
	K_{12}	N (k)	3.87 ± 1.22	1.64 ± 0.41	1.50 ± 0.44	2.36	3.67
		N ± Mg	3.92 ± 1.26	1.72 ± 0.60	1.45 ± 0.37	2.28	3.89
		N ± Mg ± PK	3.83 ± 1.27	1.70 ± 0.44	1.48 ± 0.26	2.25	3.74

Thus, before the foliar fertilisation, the content of chlorophyll *a* in the leaves of winter wheat plants of Shestopalivka variety was 15% higher, and carotenoids – 16% higher compared to Mason variety. At the same time, the content of chlorophyll *b* was higher in Mason variety by 17%, which may be due to the adaptation of plants of this variety to a lack of light (Klipakova et al, 2021). The ratio Chl *a* / Chl *b* confirms this conclusion.

Pre-sowing potassium fertilisation led to a decrease in the concentration of pigments at the stage of BBCH 31 in the leaves of both varieties of winter wheat, which can be explained by the active growth of the leaf surface area and their corresponding growth dilution.

On day 3 after the foliar fertilisation (Table 2), a decrease in the pigment content in the leaves of plants of all experimental variants was observed, which was again due to the active growth of the photosynthetic surface and a decrease in the total dry matter mass. At the same time, there was no significant difference between varieties in the content of photosynthetic pigments during this period.

Table 2. The state of the pigment complex of winter wheat plants at stage BBSN 31 on the 3rd day after foliar fertilisation, the average for 2020-2021

Cultivar (factor A)	Pre-sowing fertilisation (factor B)	Foliar fertilisation (factor C)	Pigment content, mg/g of dry matter			(chl.*a*)/ (chl.*b*)	chl/car
			chlorophyll *a*	chlorophyll *b*	carotenoids		
Shestopalivka	K_0	N (k)	3.67 ± 0.92	1.79 ± 0.49	1.50 ± 0.87	2.05	3.64
		N ± Mg	3.99 ± 0.83	1.89 ± 0.73	1.79 ± 0.25	2.11	3.28
		N ± Mg ± PK	4.29 ± 0.86	1.96 ± 0.46	1.55 ± 0.24	2.19	4.03

Table 2, Continued

Cultivar (factor A)	Pre-sowing fertilisation (factor B)	Foliar fertilisation (factor C)	Pigment content, mg/g of dry matter			(chl.*a*)/ (chl.*b*)	chl/car
			chlorophyll *a*	chlorophyll *b*	carotenoids		
Shestopalivka	K_{12}	N (k)	3.81 ± 0.83	1.75 ± 0.29	1.93 ± 0.12	2.18	2.88
		N ± Mg	4.08 ± 0.78	1.78 ± 0.54	1.76 ± 0.04	2.29	3.33
		N ± Mg ± PK	4.19 ± 0.24	1.80 ± 0.50	1.74 ± 0.25	2.33	3.44
Mason	K_0	N (k)	3.50 ± 0.57	1.74 ± 0.41	1.51 ± 0.28	2.01	3.47
		N ± Mg	3.68 ± 0.68	2.01 ± 0.52	1.80 ± 0.21	1.83	3.16
		N ± Mg ± PK	4.19 ± 0.75	2.05 ± 0.31	1.47 ± 0.16	2.04	4.24
	K_{12}	N (k)	3.61 ± 0.74	1.87 ± 0.74	1.55 ± 0.22	1.93	3.54
		N ± Mg	3.99 ± 0.70	1.96 ± 0.38	1.69 ± 0.20	2.04	3.52
		N ± Mg ± PK	4.11 ± 0.54	1.98 ± 0.33	1.60 ± 0.23	2.08	3.81

Notably, on the 3rd day after fertilisation, as opposed to the previous period, there was no significant difference in pigment content between the variants with pre-sowing potash fertilisation and those without such agricultural practices.

Foliar fertilisation of plants contributed to the growth of both chlorophylls and carotenoids in the leaves of plants of both studied varieties. Moreover, the highest efficiency of this agricultural practice was observed in the variants of complex application of urea with magnesium sulfate and potassium monophosphate both on the background of pre-sowing fertilisation with potassium fertilisers and without it.

During this period, the Chl. *a* / Chl. *b* ratio decreased by 6-39% compared to the previous stage, depending on the experimental variant, resulting from an increase in the content of chlorophyll *b* in response to an increase in leaf surface area and deterioration of lighting conditions. The complex application of foliar fertilisers (N + Mg + PK) against the background of pre-sowing K_{12} fertilisation contributed to a more stable performance of the photosynthetic apparatus of plants of both studied varieties, as a result of which the indicated chlorophyll ratio differed only by 6-8% compared to the previous period.

On day 10 after the foliar fertilisation treatment, an increase in chlorophyll content was observed (Table 3), which indicates a gradual adaptation of the photosynthetic apparatus of winter wheat plants to the habitat conditions.

Moreover, the Shestopalivka variety showed an increase in both chlorophyll *a* and chlorophyll *b* content by 6-22% and 3-7%, respectively, depending on the treatment option, compared to the previous stage.

At the same time, the Mason variety was characterised by an increase in the content of only chlorophyll *b* by 9-32% compared to day 3 after fertilisation.

Table 3. The state of the pigment complex of winter wheat plants at stage BBSN 31 on the 10th day after foliar fertilisation, the average for 2020-2021

Cultivar (factor A)	Pre-sowing fertilisation (factor B)	Foliar fertilisation (factor C)	Pigment content, mg/g of dry matter			(chl.*a*)/ (chl.*b*)	chl/car
			chlorophyll *a*	chlorophyll *b*	carotenoids		
Shestopalivka	K_0	N (k)	4.47 ± 0.14	1.96 ± 0.10	1.48 ± 0.01	2.28	4.34
		N ± Mg	4.80 ± 0.49	1.94 ± 0.17	1.94 ± 0.10	2.47	3.47
		N ± Mg ± PK	5.08 ± 0.32	2.06 ± 0.04	1.56 ± 0.14	2.47	4.58
	K_{12}	N (k)	4.30 ± 0.14	1.92 ± 0.11	1.74 ± 0.09	2.24	3.57
		N ± Mg	4.32 ± 0.25	1.94 ± 0.15	1.63 ± 0.30	2.23	3.84
		N ± Mg ± PK	4.80 ± 0.07	2.11 ± 0.09	1.59 ± 0.05	2.27	4.35
Mason	K_0	N (k)	3.56 ± 0.22	1.90 ± 0.24	1.48 ± 0.04	1.87	3.69
		N ± Mg	3.80 ± 0.14	2.40 ± 0.28	1.65 ± 0.15	1.58	3.76
		N ± Mg ± PK	4.38 ± 0.29	2.60 ± 0.13	1.45 ± 0.06	1.68	4.81
	K_{12}	N (k)	3.79 ± 0.67	2.08 ± 0.27	1.51 ± 0.27	1.82	3.89
		N ± Mg	4.05 ± 0.90	2.42 ± 0.39	1.77 ± 0.27	1.67	3.66
		N ± Mg ± PK	4.37 ± 0.67	2.62 ± 0.22	1.59 ± 0.30	1.67	4.40

Foliar fertilisation of winter wheat plants with phosphorus-potassium fertilisers (N + Mg + PK) contributed to a further increase in chlorophyll *a* content by 12-23% and chlorophyll *b* by 5-37% depending on the variety, as compared to the control. Meanwhile, the highest efficiency of this agricultural practice was achieved with the Mason variety both with and without potash fertilisers.

The content of carotenoids remained largely the same as in the previous analysed period, which also confirms the stable performance of the leaf apparatus at this stage of plant development.

This stage of development was characterised by an increase in the ratio of chlorophylls to carotenoids (Chl./car.) – from 2.88-4.24 on day 3 after fertilisation to 3.47-4.81 on day 10, which indicates the predominance of green pigments in the photosynthetic apparatus of winter wheat plants and its active functioning.

The light-harvesting complex (LHC) characterises the number of chlorophylls engaged in the transfer of absorbed energy to the pigment-protein complex and plays an important role in the regulation of the light stage of photosynthesis. As demonstrated by the data obtained, foliar fertilisation of winter wheat plants at the stage of BBCH 31 contributed to an increase in the number of pigments entering the LHC on day 3 with a gradual decrease in their content on day 10 (Fig. 1). This surge in the activity of sunlight absorption by pigments is most likely attributed to an increase in the activity of the plant enzyme system as a result of foliar fertiliser (Bilousova et al, 2019).

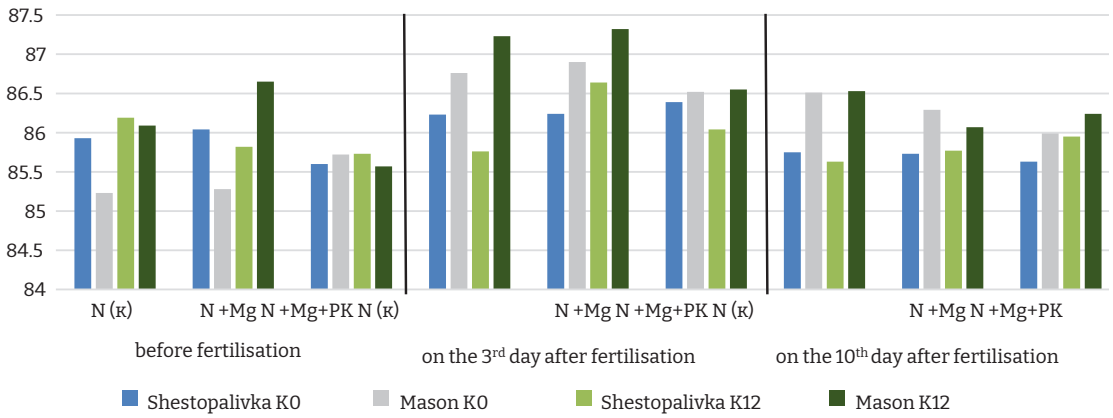

Figure 1. The activity of the light-harvesting complex of winter wheat plants depending on the studied factors, the average for 2020-2021, %

The highest activity of LHC at all analysed stages was observed for Mason plants, which may be the result of adaptation to deteriorating lighting conditions due to active growth of leaf surface area and is consistent with the information presented above.

CONCLUSIONS

The results of the conducted research indicate the high efficiency of the complex application of nitrogen-phosphorus-potassium fertilisers for foliar fertilisation of winter wheat plants at the stage of BBCH 31 both on the background of pre-sowing application of potassium fertilisers and without it. Thus, this agricultural technique resulted in a 10-17% increase in chlorophyll *a* and a 3-10% increase in chlorophyll b content for Shestopalivka variety compared to the control. At the same time, for Mason, this increase was 14-23% and 6-37%, respectively.

The adjustment of the plant nutrition system at different stages of growth and development helps to increase the content of photosynthetic pigments in the leaves of winter wheat plants, which in the future affects plant yield and the quality of the grain.

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Особливості пігментного комплексу рослин пшениці озимої залежно від способу удобрення

Анотація. Для отримання максимальної врожайності озимої пшениці необхідна подальша оптимізація сучасних технологій вирощування з метою їх адаптації до мінливих умов навколишнього середовища. Одним із аспектів адаптації рослин до несприятливих абіотичних факторів є активне функціонування фотосинтетичного апарату, яке залежить від кількості внесених поживних речовин. У роботі досліджено вплив удобрення на стан пігментного комплексу рослин озимої пшениці в умовах Південного Степу України. Для дослідження було обрано два сорти озимої пшениці: Шестопалівка та Мейсон. Схема досліду включала внесення добрив під час сівби ($К_0$; $К_{12}$) та позакореневі обробки різними баковими сумішами (карбамід; карбамід + сульфат магнію; карбамід + сульфат магнію + монофосфат калію). Вміст пігментів визначали шляхом подрібнення свіжого листя озимої пшениці з подальшим додаванням розчинника у вигляді ацетону. Вміст пігментів вимірювали за допомогою спектрофотометра. Результати досліджень показали, що до позакореневого підживлення вміст хлорофілу *a* та каротиноїдів був вищим у листках рослин сорту Шестопалівка. Водночас вміст хлорофілу *b* був вищим у рослин сорту Мейсон на 17%, що може бути наслідком адаптації рослин цього сорту до нестачі світла. На 3-й день після позакореневого підживлення спостерігалося зниження вмісту пігментів у листках рослин усіх дослідних варіантів, що пов'язано з активним ростом фотосинтезуючої поверхні та зменшенням загальної маси сухої речовини. Суттєвої різниці між сортами за вмістом фотосинтетичних пігментів у цей період не спостерігалося. На 10-ту добу після позакореневого підживлення спостерігали збільшення вмісту хлорофілу a і b для обох досліджуваних сортів, що може бути наслідком адаптації фотосинтетичного апарату рослин пшениці озимої до умов освітлення. Позакореневе підживлення рослин пшениці озимої баковою сумішшю карбаміду з сульфатом магнію та монофосфатом калію сприяло подальшому підвищенню вмісту хлорофілу a на 12-23% та хлорофілу b на 5-37% залежно від сорту порівняно з контролем. Результати проведених досліджень свідчать про високу ефективність комплексного застосування азотно-фосфорно-калійних добрив для позакореневого обприскування рослин пшениці озимої у фазі ВВСН 31 як на фоні передпосівного внесення калійних добрив, так і без нього

Ключові слова: *Triticum aestivum*, позакореневе підживлення, хлорофіли a і b, каротиноїди, ЛГК

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The Influence of Nanoparticles, Multicomponent Microelemental Fertiliser "Avatar-2 Zahyst" and Microbial Fertiliser "Azogran" on the Yield of Potato Variety "Suvenir Chernihivsky" in Polissya

Abstract. Improving traditional potato growing technology is of great scientific and practical importance for agriculture. Recently, nanoparticles (NPs) have been catching the attention of scientists as a promising means of increasing crop productivity. It has been established that NPs of such chemical elements as Fe, Zn, B, Si, Cu, Co, Se, and Ag can significantly increase the productivity of potatoes. It is known that Ag NPs show synergism with some microbial agents. However, the effect of NP of such elements as Zn and Se on potato yield and NPs combined with microbial agents for pre-sowing fertilisation has not been studied sufficiently. The influence of Ti and I NPs on potato yield, the influence of ELs on the yield of domestic potato varieties, and the influence of ELs on potato yield in Polissya are not yet studied. The purpose of the study was to investigate the effect of pre-sowing fertilisation of potatoes with Zn NPs, Ti NPs, Se + I NPs, Zn + Ti + Se + I NPs, multicomponent microelement fertiliser "Avatar-2 Zahyst", microbial fertiliser "Azogran" and a combination of microbial fertiliser "Azogran" with Se + I NPs on the yield of potato variety "Suvenir Chernihivsky" in Polissya. For three years in a row, small-scale experiments were set up on sod-podzolic soil and leached chernozem. The plots were located on the land of the Institute of Agricultural Microbiology and Agricultural Production of the National Academy of Agrarian Sciences in Chernihiv Oblast. The data obtained on the potato harvest was analysed in accordance with generally accepted methods of statistical analysis. It was found that among all variants of pre-sowing fertilisation, the composition of Se + I NPs, the microbial fertiliser Azogran and the combination of Azogran with the composition of Se + I NPs had the greatest effect on the yield

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of potatoes of the Suvenir Chernihivsky variety on sod-podzolic soil by 33.13, 38.34 and 45.35%, respectively, and on leached chernozem by 10.97, 17.98 and 37.27%. It was found that the composition of Se + I nanoparticles and Azogran exhibit synergism. The data obtained indicate high prospects for the use of NPs in combination with microbial fertilisers in potato cultivation

Keywords: potatoes, crop, nanotechnology, nanoparticles, microbial fertiliser, microelement fertiliser

RELEVANCE

Potatoes are one of the most important food, technical and fodder crops in Ukraine and around the world. Improving conventional potato growing methods is an important task for agricultural production. Among the latest methods of improving the technology of growing potatoes, nanotechnologies occupy an important place. Numerous studies have established the positive effect of nanoparticles (NPs) of various chemical elements and compounds on the productivity of plants, in particular, potatoes.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The study of the effect of NPs on the growth of plants, in particular potatoes, is an extremely relevant area of modern science. It is established that the NPs of many chemical elements, including metals, nonmetals, and semi-metals, can significantly increase potato yield, reduce plant disease, and increase the nutritional value of tubers.

Fe NFs have been shown to increase the mineral content of potato tubers, leaf growth rate, weight and uniformity of tuber size, ripening rate, potato yield, and a number of other important indicators (Davies, 2018). Zn, B, Si, and zeolite NPs have been proven to increase the yield of potato tubers (Mahmoud, 2020).

It was found that Fe, Cu, Co, and CuO have a positive effect on the area of leaf blades of potato plants, tuber yield, number of tubers per plant, the average weight of 1 tuber, and the content of starch, vitamin C, and vitamin PP in tubers (Samoylova *et al.*, 2017). Se NPs were found to increase the ability of potato leaves to retain moisture and resistance to elevated temperatures and increase potato yields (Cherniakova *et al.*, 20 19).

According to the results of research, Ag NPs in combination with the microbial fertiliser Nitroxin, which contains strains of nitrogen-fixing bacteria of the species *Enterobacter cloacae* and genera *Pseudomonas* and *Azotobacter*, increases the size of minitubers, the number of minitubers per plant, the average weight of 1 minituber and the yield of potato minitubers (Davod *et al.*, 2011). It was found that hybrid stabilized polyhexamethylene biguanide with Ag hydrochloride increases the yield and marketability of potato tubers (Krutyakov *et al.*, 2017). Under *in vitro* conditions, Ag NPs at certain concentrations reduced the length of potato stems but significantly increased the length of roots, leaf area, and dry weight of stems and roots. In addition, Ag NFs increased the total content of chlorophyll, anthocyanins, flavonoids, and phenols. The content of proline did not change. Ag NPs slightly increased H_2O_2 concentration in potato plant tissues and lipid peroxidation (Homaee & Ehsanpour, 2015).

It has been established that SiO_2 NPs at certain concentrations increase the weight of potato stems and leaves, the number and weight of tubers per plant, the content of chlorophyll and carotenoids, and do not affect the electrophoretic mobility of DNA, which indicates the absence of toxicity (Mushinskiy *et al.*, 2018).

It has been found that Na_2SiO_3 NPs increase the quantum yield of photosystem II, carotenoid content in potato tissues, the antioxidant activity of 1,1-diphenyl-2-picrylhydrazyl, number of tubers per plant, tuber yield, and dry matter content in tubers (Kafi *et al.*, 2019).

Therefore, the use of nanoparticles in potato growing technology has prospects. However, the effect of Zn, Ti, Se, I NPs, their compositions and preparations developed on the basis of a wide range of nanoparticles, and the simultaneous use of nanoparticles and microbial preparations have not been sufficiently studied.

The purpose of the study was to investigate the effect of pre-sowing fertilisation with Zn NPs, Ti NPs, Se + I NPs, Zn + Ti + Se + I NPs, "Avatar-2 Zahyst", microbial fertiliser "Azogran" and a combination of "Azogran" with Se + I NPs on the yield of potato variety "Suvenir Chernihivsky" in Polissya.

MATERIALS AND METHODS

The experiments used Zn NPs, Ti NPs, Se + I NPs composition and multicomponent microelement fertiliser "Avatar-2 Protection" developed by Doctor of Technical Sciences, Professor V. Kaplunenko, courtesy of V. Dimchev (Avatar Research and Production Company LLC), the microbial fertiliser "Azogran" courtesy of Doctor of Biological Sciences, Professor, Head of the Department of Microbiological Processes on Hard Surfaces of the D. K. Zabolotny Institute of Microbiology and Virology of the NAS of Ukraine, I. K. Kurdysh, for which the author expresses his sincere gratitude.

Multicomponent micronutrient fertiliser Avatar-2 Zahyst is designed to protect crops from fungal, bacterial and viral pathogens. The fertiliser contains NPS of at least 13 chemical elements and has fungicidal, bactericidal and insecticidal activity. Avatar-2 Zahyst is a stress protector and helps to increase plant resistance to drought, snowless frosts, and soil salinity (Kaplunenko *et al.*, 2017; Derevianko *et al.*, 2019).

"Azogran" is a complex bacterial fertiliser containing selected strains of nitrogen-fixing bacteria *Azotobacter vinelandii* IMB B-7076 and phosphate-mobilising bacteria *Bacillus subtilis* IMB B-7023. The fertiliser has growth-regulating and insecticidal effects, increases crop productivity and improves the germination of forest crop seedlings (Korniychuk *et al.*, 2018; Kurdysh *et al.*, 2021).

To study the effect of NPs and Avatar-2 Zahyst and Azogran on the yield of potatoes of the Suvenir Chernihivsky variety, two small-plot experiments were laid out on the land plots of the Institute of Agricultural Microbiology and Agroindustrial Production of the National Academy of Sciences of Ukraine (IAMAP NAS). The first plot has sod-podzolic soil, and the second has leached chernozem.

The soddy-podzolic soil had the following initial agrochemical characteristics of the arable layer: humus content (by Tyurin) – 1.1%; pH of the salt extract – 5.0; hydrolytic acidity (by Kappen) – 2.5 m-eq. per 100 g; P_2O_5 content (by Kirsanov) – 170.0; K_2O (by Maslova) – 62.0 mg per 1 kg of soil (Volkohon *et al.*, 2013).

The leached chernozem had the following initial agrochemical characteristics of the arable layer: humus content was 3.56%; pH_{KCl} was 5.2-5.5; the sum of absorbed bases was 12.5-14.0 mg-eq. per 100 g of soil; the content of easily hydrolyzed nitrogen (by Cornfield) was 95-100 mg; mobile phosphorus forms (by Kirsanov) were 108-111 mg K_2O per 1 kg of soil (Kopylov *et al.*, 2009).

Following generally accepted methods, a plot size of 9.8 m^2 was selected (Dospekhov, 1985). The total area of both experiments was 410 m^2 each. Both experiments were repeated four times. Agricultural techniques used on the plots are shown in Table 1.

Table 1. Agricultural techniques used in the experimental plots

Agrotechnics	Plot on sod-podzolic soil	Plot on leached chernozem
Tillage	Disking, cutting ridges	Disking, cutting ridges
Mineral fertiliser application (y/y)	$N_{96}P_{96}K_{96}$ (ANP fertilizer)	$N_{96}P_{96}K_{96}$ (ANP fertilizer)
Application of organic fertilisers	not applied	not applied
Seeding rate	41,000 tubers/ha	41,000 tubers/ha
Row spacing width	70 cm	70 cm

In different variants of the experiment, Zn NC, Ti NC, Se + I NPs composition, Zn + Ti + Se + I NPs composition, microbial fertiliser Azogran, and a combination of Azogran and Se + I NPs composition were used. To assess their performance, pre-sowing treatment of potato seeds with solutions of these compounds was used.

The placement of variants is systematic two-tier and systematic multi-tier. The pre-sowing fertilisation of potato seeds was carried out according to the scheme shown in Table 2.

The data on temperature and precipitation during the period of the experiment are shown in Table 3.

Table 2. Scheme of small plot experiments

Variant	Load, l/t	Solution/fertiliser concentration	Concentration (per 1 tuber)
Control (Running water)	1	-	-
Zn NPs	1	4000 mg/l	97.6 µg
Ti NPs	1	500 mg/l	12.2 µg
Se + I NPs	1	100 + 150 mg/l	2.4 + 3.7 µg
Zn + Ti + Se + I NPs	1	Zn NPs: 4000 mg/l Ti NPs: 500 mg/l Se + I NPs: 100 + 150 mg/l	Zn NPs: 97.6 µg Ti NPs: 12.2 µg Se + I NPs: 2.4 + 3.7 µg
Avatar-2 Zahyst fertiliser	1	-	24.4 µL
Azogran fertiliser	1	*B. subtilis*: $1x10^9$ CFU/cm^3 *A. vinelandii*: $1x10^8$ CFU/cm^3	*B. subtilis*: $2,4x10^7$ CFU *A. vinelandii*: $2,4x10^6$ CFU
Combination of the fertiliser "Azogran" with Se + I NPs	1	*B. subtilis*: $1x10^9$ CFU/cm^3 *A. vinelandii*: $1x10^8$ CFU/cm^3 Se + I: 100 + 150 mg/l	*B. subtilis*: $2,7x10^7$ CFU *A. vinelandii*: $2,4x10^6$ CFU Se + I: 2.4 + 3.7 µg

Table 3. Weather conditions in 2021

Month	Precipitation, mm		Average daily air temperature, t °C	
	Average data for 2019-2021 (M * ± Std.Err**)	Medium-long-term data	Average data for 2019-2021 (M ± Std.Err)	Medium-long-term data
April	8.4 ± 0.6	9.0	29 ± 5	36
May	14.2 ± 1.3	15.0	87 ± 13	63
June	21.6 ± 0.6	18.6	45 ± 22	62
July	20.7 ± 1.5	20.5	57 ± 5	74
August	19.4 ± 0.4	19.3	52 ± 8	54
September	14.2 ± 1.1	13.8	39 ± 2	53

Note: *M – arithmetic mean; **Std.Err – standard error of the arithmetic mean

To record the harvest, 10 separately located bushes were dug up from each plot (Dospiekhov, 1985; Bondarchuk *et al.*, 2019) and the total weight of tubers from each bush was weighed. The total weight of tubers from each bush was converted to t/ha using the formula:

$$x = \frac{(m \times 41000)}{1000000}, (1)$$

Where x is the yield, t/ha, m is the weight of tubers per bush, g, 41,000 is the seeding rate, tubers/ha, 1,000,000 is the number of grams in 1 ton.

The obtained yield values were entered into spreadsheets for further statistical analysis.

The obtained data on the yield of potato variety Suvenir Chernihivskyi were analysed according to the generally accepted methods of statistical analysis (Rebrova, 2002) using Microsoft Office Excel 2016, StatSoft STATISTICA 10 and StatSoft STATISTICA 12. First, the data in all variants were analysed for compliance with the normal (Gaussian) distribution using the Kolmogorov-Smirnov, Lilliefors, and Shapiro-Wilk tests. It was found that in the vast majority of cases, the data distribution differs from the normal distribution in all tests, so nonparametric statistical methods were used for further analysis. The median was calculated to show the average yield in the variants. The significance of the difference between the experimental variants and the control (p) was calculated using the nonparametric Shapiro-Wilk U-test (Rebrova, 2002).

RESULTS AND DISCUSSION

It was found that the effect of the studied NFs and the microbial fertiliser Azogran on the potato yield varies according to the chemical composition of the NFs and differs slightly depending on the soil.

On soddy podzolic soil, most of the pre-sowing fertiliser variants contributed to the growth of the yield of potato tubers of the Suvenir Chernihivsky variety. However, when subjected to Zn and Ti NPs, there was a downward trend in yield in the last two years (Table 4).

The pre-sowing fertilisation with the composition of Se + I NPs resulted in a growing tendency of potato tubers yield of the variety Suvenir Chernihivsky. Thus, in the first year, the harvest grew significantly by 49.22%, in the second year it decreased by 8.85%, and in the third year, it grew by 8.35%. According to the average data of three years, after pre-sowing fertilisation with Se + I NPs composition the yield significantly increased by 33.13% (Table 4).

The variants with Azogran showed an increase in yield. During the first year, the yield after pre-sowing treatment with Azogran increased significantly by 23.39%, in the second year it decreased by 6.44%, and in the third year it increased by 6.09%.

According to the average data of three years, after pre-sowing fertilisation with Azogran the yield increased significantly by 38.34% (Table 4).

Table 4. The yield of Suvenir Chernihivsky potato variety after pre-sowing fertilisation with nanoparticles, multicomponent microelement fertiliser "Avatar-2 Zahyst" and microbial fertiliser "Azogran" on a plot with sod-podzolic soil, t/ha

Variant	Average yield, t/ha (median)			
	2019	2020	2021	Average for 2019-2021
Control	23.55	35.04	13.51	19.21
Zn NPs	26.65	32.67	11.58	23.12

Table 4, Continued

Variant	Average yield, t/ha (median)			
	2019	2020	2021	Average for 2019-2021
Ti NPs	25.57	24.51*	12.57	21.66
Se + I NPs	35.14*	31.94	14.64	25.57*
Zn + Ti + Se + I NPs	25.98	29.39	13.98	22.48
Avatar-2 Zahyst fertiliser	26.47*	29.73	15.46	23.71
Azogran fertiliser	29.06*	32.78	14.33	26.57*
Azogran + Se + I NPs composition	32.29*	44.65*	18.45*	27.92*

Note: The * sign within the same column indicates significant differences between the variants relative to the control at a significance level of $p < 0.05$ according to the Mann-Whitney U test

The highest yield was obtained with the simultaneous pre-sowing fertilisation of Suvenir Chernihivsky variety potato seeds using Azogran with the composition of Se + I NPs. The yield in this variant increased significantly throughout the observation period. In the first year, the yield was 37.09% higher than in the control, and in the second and third years, it was 27.43% and 36.57% higher, respectively. According to the average data of three years, with pre-sowing fertilisation with "Azogran" and Se + I NPs composition significantly increased by 45.35% (see table. 4).

The pre-sowing fertilization of potato seeds with Zn, LF Ti, LF Zn + Ti + Se + I NPs composition and "Avatar-2 Zahyst" fertiliser exhibited a tendency to increase the yield, but the results were not significant (see Table 4).

According to the results of statistical analysis, all variants of leached chernozem demonstrated a more distinct upward trend in yield (see Table 4).

As opposed to the sod-podzolic soil, a significant upward trend in yield was observed on the leached chernozem after pre-sowing fertilisation with Zn NPs. The yield in this variant increased significantly by 24.85 and 30.35% in the first and second years, and by 5.24% in the third year (Table 5).

Table 5. The yield of Suvenir Chernihivsky potato variety after pre-sowing fertilisation with nanoparticles, multicomponent microelement fertiliser "Avatar-2 Zahyst" and microbial fertiliser "Azogran" on a plot with leached chernozem, t/ha

Variant	Average yield, t/ha (median)			
	2019	2020	2021	Average for 2019-2021
Control	13.79	21.76	15.33	16.37
Zn NPs	17.23*	28.37*	16.32	17.23
Ti NPs	19.18*	21.29	14.72	17.38
Se + I NPs	20.29*	23.03	16.69	18.16*

Table 5, Continued

Variant	Average yield, t/ha (median)			
	2019	2020	2021	Average for 2019-2021
Zn + Ti + Se + I NPs	19.35*	26.51*	15.01	18.37
Azogran fertiliser	20.49*	27.82*	17.02	19.31*
Avatar-2 Zahyst fertiliser	18.69*	23.83*	16.29	17.96*
Azogran + Se + I NPs composition	23.51*	26.34*	19.80*	22.47*

Note: The * sign within the same column indicates significant differences between the variants relative to the control at a significance level of $p < 0.05$ according to the Mann-Whitney U test

The variant with pre-sowing fertilisation with Ti NPs showed a downward trend in yield. In the first year, the harvest in this variant increased by 39.05%, in the second year it decreased by 2.16%, and in the third year it decreased by 4.01%. According to the average data of three years, the harvest in this variant increased by 6.21% (see Table 5).

Under pre-sowing fertilization with Se + I NPs, a tendency towards yield increase was observed. Thus, in the first year, the harvest in this variant increased by 47.04%, in the second – by 5.83%, in the third – by 8.82%. According to the average data of three years, the yield in this variant is 10.97% higher than the control with a sufficient level of significance (see Table 5).

An upward trend in yield was also observed in the variants with pre-sowing fertilisation with the composition of Zn + Ti + Se + I NPs and fertiliser Avatar-2 Zahyst. According to the average data of three years, the yield in these variants increased by 12.21% and 9.71%, respectively (see Table 5).

In the variant with pre-sowing fertiliser with "Azogran", the yield was steadily increasing. Thus, in the first and second years, the yield in this variant was significantly higher than in the control by 48.52 and 27.86%, respectively, and in the third year – by 10.96%. According to the average data of three years, the yield in this variant is significantly higher than in the control by 17.98% (see Table 5).

The best results were obtained with pre-sowing fertilisation with a combination of Azogran and Se + I NPs composition, which was characterised by the greatest impact on the yield. The yield in this variant increased significantly by 70.41, 21.06, and 29.14%, respectively, for three consecutive years. According to the average data of three years, the yield in this variant is significantly higher than in the control by 37.27% (Table 5).

The difference in data obtained from the two sites is consistent with data from other researchers. It is known that the biological activity of NPs can vary depending on the type of soil. Thus, the same NPs can stimulate or inhibit the activity of dehydrogenase, urease, acid and alkaline phosphatase, depending on the type of soil (Jośko, 2014).

Consequently, the Ti NPs showed a tendency to reduce the yield on both soils, the Zn NPs – to reduce the yield on sod-podzolic soil and to increase on leached chernozem. The composition of the Zn + Ti + Se + I NPs exhibited a tendency to a slight increase in yield.

The composition of Se + I NPs, Avatar-2 Zahyst and Azogran had a greater impact on the yield of potatoes of the Suvenir Chernihivsky variety.

The combination of Azogran with the composition of Se + I NPs had the greatest effect on the yield, steadily increasing its growth in both plots throughout the entire observation period. The results obtained indicate a significant synergy between the composition of the SE + I NPs and the microbial fertiliser Azogran. S. Derevianko and A. Vasylchenko (2020) found that the composition of Se + I Nps significantly increases the titer of the bacterial strain *Bacillus subtilis* IMB B-7023, which is one of the bioagents of the fertiliser Azogran, which may explain the synergy (Derevianko & Vasylchenko, 2020). The authors believe that the use of NPs, in particular in combination with microbial preparations, can significantly increase the efficiency of potato cultivation.

CONCLUSIONS

It was found that the studied NPs influence the yield of potatoes of the Suvenir Chernihivsky variety in different ways. The effect of NPs on yields may differ slightly depending on the type of soil in which the experiment is conducted, but the overall trends are the same on both soils.

Pre-sowing fertilisation with Ti NPs results in a decrease in the yield of potatoes of the Suvenir Chernihivsky variety. In the last two years of observation, the yield decreased when fertilised with Zn NPs on sod-podzolic soil, but increased steadily on leached chernozem. The composition of Zn + Ti + Se + I NPs and the multicomponent micronutrient fertiliser "Avatar-2 Zahyst" increase the yield of potatoes of the variety Suvenir Chernihivsky, but not enough statistically significant data were obtained during the observation period.

The composition of Se+I NPs and the microbial fertiliser "Azogran" significantly increase the yield of potatoes of the Suvenir Chernihivsky variety. According to the average data of three years, pre-sowing fertilisation with the composition of Se + I NPs and the microbial fertiliser "Azogran" contributed to a significant increase in yield on sod-podzolic soil by 33.13 and 38.34%, respectively, and on leached chernozem by 10.97 and 17.98%, respectively.

According to the research, the best variant of pre-sowing fertilisation, which has the most significant effect on the yield of potatoes of the variety Suvenir Chernihivsky, is a combination of "Azogran" with the composition of Se + I NPs. This variant contributed to a statistically significant increase in yield throughout the entire monitoring period in both plots. According to the average data of three years, the yield in this variant is significantly higher than in the control by 45.35% on sod-podzolic soil and by 37.27% on leached chernozem.

The data obtained indicate a significant synergy between the composition of Se + I NPs and the microbial preparation "Azogran", which can be explained by the stimulating effect of Se + I NPs on the bioagent strains of the fertiliser.

The findings of the study suggest that the introduction of nanotechnology and its combined use with microbial preparations is promising for increasing potato yields.

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Вплив наночастинок, багатокомпонентного мікроелементного добрива «Аватар-2 Захист» та мікробного добрива «Азогран» на врожайність картоплі сорту Сувенір Чернігівський в умовах Полісся

Анотація. Удосконалення традиційних технологій вирощування картоплі має велике наукове і практичне значення для сільського господарства. Останнім часом наночастинки (НЧ) привертають увагу вчених як перспективний засіб підвищення продуктивності сільськогосподарських культур. Встановлено, що НЧ таких хімічних елементів, як Fe, Zn, B, Si, Cu, Co, Se та Ag можуть значно підвищити врожайність картоплі. Відомо, що НП Ag проявляють синергізм з деякими мікробними агентами. Однак вплив на врожайність картоплі таких елементів, як Zn і Se, та їх поєднання з мікробіологічними препаратами для передпосівного удобрення вивчено недостатньо. Не вивчено вплив NP Ti та I на врожайність картоплі, вплив ЕМ на врожайність вітчизняних сортів картоплі, а також вплив ЕМ на врожайність картоплі в умовах Полісся. Метою роботи було дослідити вплив передпосівного підживлення картоплі NPK Zn, NPK Ti, Se+I NPK, Zn+Ti+Se+I NPK, багатокомпонентного мікроелементного добрива "Аватар-2 Захист", мікробного добрива "Азогран" та комбінації мікробного добрива "Азогран" з Se+I NPK на врожайність картоплі сорту "Сувенір Чернігівський" в умовах Полісся. Три роки поспіль на дерново-підзолистому ґрунті та чорноземі вилугуваному закладали невеликі досліди. Ділянки були розташовані на землях Інституту сільськогосподарської мікробіології та агропромислового виробництва Національної академії аграрних наук у Чернігівській області. Отримані дані про врожай картоплі аналізували відповідно до загальноприйнятих методів статистичного аналізу. Встановлено, що серед усіх варіантів передпосівного внесення добрив найбільший вплив на врожайність картоплі сорту Сувенір Чернігівський на дерново-підзолистому ґрунті мали композиція Se+I NP, мікробне добриво Азогран та поєднання Азограну з композицією Se+I NP на 33,13, 38,34 та 45,35% відповідно, а на чорноземі вилугуваному - на 10,97, 17,98 та 37,27%. Встановлено, що композиція наночастинок Se+I та азограну проявляє синергізм. Отримані дані свідчать про високу перспективність використання НЧ у поєднанні з мікробними добривами при вирощуванні картоплі

Ключові слова: картопля, культура, нанотехнології, наночастинки, мікробне добриво, мікроелементне добриво

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The Effect of Fertilisation on the Nutritional Value of Alfalfa-Grass Mixtures in the Right-Bank Forest-Steppe

Abstract. One of the ways to reduce protein deficiency and produce complete feed is the cultivation of alfalfa-grass mixtures, which, due to the optimal ratio of protein and carbohydrate compounds, mineral salts and other valuable biologically active substances, most fully meet the physiological needs of animals. The purpose of the research was to determine the effect of mineral fertilisers on the nutritional value of alfalfa-cereal grass mixtures. Experimental studies were conducted during 2014-2016 on the experimental field of the Department of Feed Production, Land Reclamation and Meteorology, which is located in the SE NUBiP of Ukraine "Agronomic Research Station" on typical

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low humus black soil. The results of the conducted research revealed that the inclusion of alfalfa in cereal grass stands increases the content of crude protein to a greater extent than the application of nitrogen at the rate of N_{60} on the same cereal grass stand on the same background of $P_{60}K_{90}$. There were no significant differences in crude protein accumulation between alfalfa-grass stands with different cereal components on the same backgrounds. The introduction of alfalfa into grass stands promotes the growth of protein and crude fat in the feed and reduces the content of nitrogen-free extractives. The chemical composition of grass feed is most affected by nitrogen fertilisers on grass stands. With the introduction of N_{60} on the background of $P_{60}K_{90}$ the dry weight of the feed increases by 2.8% of the crude protein content and 26 g of the provision of a feed unit with digestible protein. The digestibility of the dry mass of alfalfa and legume-cereal grass stands relative to pure cereals increases by 2-5%. The composition of cereal components in legume-cereal mixtures and the fertiliser system do not significantly affect the digestibility of feed. On all studied grass stands the highest quality of forage is provided by the introduction of $N_{60}P_{60}K_{90}$+ Fumar

Keywords: alfalfa-grass mixtures, feed nutrition crude protein, crude fat, metabolisable energy

RELEVANCE

One of the urgent problems of the livestock industry in Ukraine is the lack of vegetable protein in the diet of animals. According to the zootechnical norm, each feed unit should be provided with 105-115 g of digestible protein, but in fact, it contains 30-35% less, which leads to a decrease in livestock productivity and feed overspending by more than 1.5 times (Kurgak V. H., Tovstoshkur V. M., 2010; Makarenko P.S., 2003; Petrychenko V.F. *et al.*) One of the solutions to this problem is to increase the efficiency of the use of natural fodder lands – a valuable source of cheap grass fodder, well balanced in protein, minerals and vitamins, but also a significant factor in improving the ecological situation in agricultural landscapes, as they protect soils from erosion and water sources from siltation.

In Ukraine, the area of such lands is about 7.8 million hectares, including 1 million hectares in the right-bank Forest-Steppe. However, their productivity today does not exceed 1.0-1.2 t/ha of feed units, which is several times less than their potential capabilities. Technological methods of formation of highly productive sown grass stand on natural fodder lands recommended by many scientists are too energy- and resource-consuming under modern conditions (Kovtun K. P. *et al.*, 2018; Kurgak V. G. *et al.*, 2002; Kurgak V. G., Titova V. M., 2002; Panakhid H. Ya. *et al.*, 2020; Patyka V. P. *et al.*, 2015).

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Along with the need to increase the yield of sown grasslands, it is important to obtain high-quality feed for animals The nutritional value of perennial forage grasses is significantly affected by soil conditions, species and varietal composition of grass stands, the mode of its use, fertilisation and other agrotechnical methods (Kurhak V.G., Voloshyn V. M, 2017; V. Olifirovich V.A., Veklenko U.A., 2021; Petrychenko V.F. *et al.*, 2020; Weiß K., Kalzendorf C., 2016).

An effective means of improving the quality of feed, especially in terms of protein content, is the introduction of legumes into perennial forage agrophytocenoses (Makarenko P.S., 2003). Their inclusion in the grass mixture in the

amount of 50% and more promotes intensive regrowth of plants, improves the protein content of the feed and its mineral composition, and also increases the yield of livestock products per unit of feed by 15-30% (Panakhid H.Ya. *et al.*, 2019).

With highly effective fertilisation, legume-grass stand in the conditions of the Forest-Steppe of Ukraine can provide a yield of 8.40 t/ha of dry matter, 0.97 t/ha of digestible protein and 87.5 GJ/ha of metabolisable energy. With the complex use (two mowing and further alienation of grass in the phase of pasture ripeness), the productivity of the mentioned indicators can be respectively 12.6 t/ha, 9.60, 1.12 t/ha and 136 GJ/ha of metabolic energy (Kovtun K.P., 2018).

Among perennial legumes, the leading role belongs to sowing alfalfa, which, due to the ability to actively use the moisture reserves of the autumn-winter period, even in spring drought, is able to form high yields (Kurhak V.G., Voloshyn V.M., 2017, Kovtun *et al*, 2020). Phytocenoses containing alfalfa sowing, compared to the same with the participation of meadow clover, are characterised by longer productive longevity (Kurhak V.H. Tovstoshkur V.M., 2010, Kurhak V.H. *et al*, 2020), so the share of alfalfa-grass mixtures in the structure of mown areas should reach 55-70% (Oenema O. *et al*, 2014). However, the theoretical aspects of the formation of high-productivity of mown grass stands of alfalfa sown in mixtures with various cereal components remain unclear.

Among the technological factors of increasing the productivity of sown legume-grass meadow phytocenoses, the most ambiguous is the use of mineral fertilisers, especially nitrogen fertilisers. It is determined that on poor soils, as a result of a high level of fixation of atmospheric nitrogen by legumes of symbiotic nitrogen from the atmosphere, crops form a high yield. On nitrogen-rich soils, leguminous plants largely lose their value as nitrogen fixers. In general, Meadow agrophytocenoses of various compositions respond positively to the application of mineral fertilisers (Olifirovych V.A., Veklenko Yu.A., 2021, Weiß K., Kalzendorf C., 2016).

In improving the efficiency of modern agricultural production, it is important to use growth regulators that affect protein synthesis, assimilation of nitrogen, phosphorus and potassium, positively affect the process of photosynthesis and reduce the content of nitrates in the feed.

Given their physiological characteristics, many authors (Kurhak V.G., Voloshyn V.M., 2017, Kovtun K.P. *et al.*, 2018, Olifirovych V.A., Veklenko Yu.A., 2021) propose a strategy for optimising the mineral nutrition of plants, focusing on the mandatory use of growth stimulators in modern technologies for growing crops, which will make it possible to reduce the rate of application of mineral fertilisers without reducing the level of yield and minimises the risks of environmental pollution of the environment and the resulting products. The use of growth stimulators makes it possible not only to obtain an additional 10-25% of the gross harvest of agricultural products but also reduces the content of nitrates and heavy metals in plants, as well as increases the nutritional value of grown feed (Lukyanets O.P., 2003; Panakhid H.Ya. *et al.*, 2019). Due to low production doses, growth stimulants belong to low-cost elements of agricultural technology (Kurhak V.G., Titova V.M., 2002). Their effectiveness is largely determined by the soil-climatic and agrotechnical conditions of growing crops.

The purpose of the research was to study the influence of technological measures of growing alfalfa-grass mixtures on the nutritional value of feed in the conditions of the right-bank forest-steppe.

MATERIALS AND METHODS

Experimental studies were conducted during 2014-2016 on the experimental field of the

Department of Feed Production, Land Reclamation and Meteorology, located in the SE NUBiP of Ukraine "Agronomic Research Station". The experimental scheme included the following factors: factor A – grass stand (types of grasses and seeding rate of their seeds, kg/ha): 1) alfalfa, 16; 2) alfalfa, 12 + Fescue Grass, 10 + Festuca pratensis, 8; 3) alfalfa, 10 + Fescue Grass, 10 + Dactylis glomerata, 8; 4) alfalfa, 10 + Bromus inermis, 14 + Lolium perenne, 10; 5) alfalfa, 10 + Bromus inermis, 14 + Fescue Grass, 8; 6) Bromus inermis, 14 + Fescue Grass, 8 (grass stand), control; factor B – fertiliser (nutrients and their doses): 1) no fertilisers, control; 2) $p_{60}K_{90}$; 3) $N_{60}P_{60}K_{90}$; 4) $N_{60}P_{60}K_{90}$ + Fumar growth stimulator. The area of the plot is 25 m², and the replication of the experiment is four times. The technology of growing perennial grasses, with the exception of the studied factors, is generally accepted for the Forest-Steppe of right-bank Ukraine. Phosphorus and potassium fertilisers in the norm of $P_{60}K_{90}$, according to the scheme of the experiment were applied annually in autumn. Nitrogen fertilisers at the norm of N60 were used in three doses: N_{20} in spring on permafrost soil and N_{20} – after the first and second mowing. Spraying of the grass stands with a Fumar growth stimulator was carried out at the beginning of the regrowth of grasses of each slope at a dose of 2 l/ha with water consumption of 200 l/ha during the period when cereal grasses were in the tillering phase, and alfalfa was in the shoot formation phase.

The soil of the experimental field is typical low-humus chernozem. The content of humus in the topsoil is 4.2-4.6%, mobile phosphorus (according to Machigin) – 40-55 mg/kg of soil, exchangeable potassium – 150-165 mg/kg of soil, easily hydrolysed nitrogen (according to Kornfield) – 140-160 mg/kg, pH of the salt extract – 6.7-7.0.

RESULTS AND DISCUSSION

According to the research results, it was found that the addition of alfalfa to cereals significantly improved the quality of feed (Table 1).

Table 1. Content of organic substances in feed and digestibility of alfalfa, alfalfa-grass and cereal grass depending on fertiliser, % in dry weight (average for 2014-2016)

Fertiliser	Crude protein	Protein	Crude fat	Crude fibre	rem	Digestibility, %
Alfalfa						
No fertilisers	17.5	11.8	2.5	25.1	46.7	60
$P_{60}K_{90}$	18.1	12.7	2.6	26.7	43.6	58
$N_{60}P_{60}K_{90}$	19.1	13.3	2.9	27.9	40.7	58
$N_{60}P_{60}K_{90}$ + Fumar	19.9	13.7	3.0	28.0	39.5	59
Alfalfa + Fescue Grass + Festuca pratensis						
No fertilisers	16.5	12.1	2.8	27.7	44.0	59
$P_{60}K_{90}$	17.0	12.8	3.0	28.3	42.4	58
$N_{60}P_{60}K_{90}$	17.4	13.4	3.4	28.9	41.7	58
$N_{60}P_{60}K_{90}$ + Fumar	18.4	13.6	3.5	29.0	39.6	58
Alfalfa + Fescue Grass + Dactylis glomerata						
No fertilisers	16.8	12.6	3.1	28.7	43.0	58

Table 1, Continued

Fertiliser	Crude protein	Protein	Crude fat	Crude fibre	rem	Digestibility, %
$P_{60}K_{90}$	16.9	13.0	3.3	29.0	41.3	58
$N_{60}P_{60}K_{90}$	18.4	13.7	3.5	29.5	38.8	57
$N_{60}P_{60}K_{90}$ + Fumar	18.6	13.9	3.6	29.7	38.2	57
Alfalfa + Bromus inermis + Lolium perenne						
No fertilisers	17.0	12.9	3.3	29.0	41.3	59
$P_{60}K_{90}$	17.4	13.3	3.5	29.3	40.2	58
$N_{60}P_{60}K_{90}$	18.8	13.7	3.7	29.9	41.7	58
$N_{60}P_{60}K_{90}$ + Fumar	19.1	14.1	3.7	29.4	37.8	59
Alfalfa + Bromus inermis + Fescue Grass						
No fertilisers	17.0	11.9	2.6	26.9	44.8	58
$P_{60}K_{90}$	17.3	12.4	2.9	27.7	43.1	57
$N_{60}P_{60}K_{90}$	18.7	13.0	3.0	28.6	40.5	58
$N_{60}P_{60}K_{90}$ + Fumar	19.0	13.4	3.2	28.8	39.7	58
Bromus inermis + Fescue Grass (grass stand)						
No fertilisers	11.1	9.5	3.6	29.6	47.2	55
$P_{60}K_{90}$	11.9	10.2	3.8	29.4	46.5	56
$N_{60}P_{60}K_{90}$	14.8	12.6	3.7	29.8	43.3	55
$N_{60}P_{60}K_{90}$ + Fumar	15.3	13.1	3.7	29.2	43.3	55
Zootechnical standard	14	–	3-5	25-30	–	50-70
LSD_{05}, %	0.6	0.6	0.2	0.6	0.7	2

Thus, on a nitrogen-free background (in variants without fertilisers and with the introduction of $P_{60}K_{90}$) the content of crude protein in the dry weight of feed increased from 11.1-11.9 to 16.5-17.4% or by 5.4-5.5%, and with the introduction of nitrogen (variants $N_{60}P_{60}K_{90}$ and $N_{60}P_{60}K_{90}$+ Fumar) – from 14.7-15.3 to 17.4-19.1% or by 1.7-2.7%. Thus, the increase in crude protein content on nitrogen-free backgrounds was more intense than on nitrogen backgrounds. There were no significant differences in crude protein accumulation between alfalfa-grass stands with different cereal components on the same backgrounds. In alfalfa grass on the same backgrounds of fertilisers, it was accumulated in dry weight by 0.5-1.5% more than in alfalfa-grass mixtures. The lowest amount of crude protein was observed in the grass stand – 11.1-11.9% in the variants without nitrogen and 14.7-15.3% for its introduction.

The introduction of alfalfa in the composition of the grass mixture simultaneously with the increase in crude protein content also led to an increase in protein content, crude fat, improved the digestibility of dry matter and reduced the amount of nitrogen-free extractive substances.

In the absence of nitrogen fertiliser in the grass stands of alfalfa and legume-grass mixtures, compared with the grass stand, the protein content in the dry weight of feed increased from 9.5-10.2 to 11.8-13.7% or by 2.3-3.5%, while with the introduction of nitrogen ($N_{60}P_{60}K_{90}$ and $N_{60}P_{60}K_{90}$+ Fumar) – from 12.6-13.1 to 13.0-14.1% or only by 0.4-1.1%. Thus, the increase in protein content, and crude protein, is more intense when growing plants on nitrogen-free backgrounds.

The digestibility of the dry weight of the forage of alfalfa and legume-cereal grass stands relative to pure cereal crops increased from 55-56 to 57-60% or by 2-5%. The composition of cereal components in legume-cereal mixtures and fertiliser systems did not significantly affect the digestibility of feed.

The content of nitrogen-free extractive substances under the influence of symbiotic and mineral nitrogen, in contrast to nitrogen-containing substances (crude protein and protein), decreased. Thus, in alfalfa and alfalfa-cereal grass stands, where symbiotic nitrogen has an impact, the content of rem in the dry weight of feed on backgrounds without nitrogen decreased from 46.5-47.2% to 40.2-46.7% or by 1.5-6.3%. When applying nitrogen fertilisers (variant $N_{60}P_{60}K_{90}$ compared to $P_{60}K_{90}$) on grass stands, the rem content decreased by 3.2%, while on stands with alfalfa – by 0.7-2.6%.

Among mineral fertilisers, the chemical composition of grass feed from grass stands is most affected by nitrogen fertilisers, the application of which in a dose of N_{60} on the background of $P_{60}K_{90}$, on average for all slopes, led to an increase in the dry weight of feed, first of all, the content of nitrogen-containing substances, in particular, crude protein – from 11.9 to 14.7%, or by 2.8%, and protein – from 10.2 to 12.6%.

In alfalfa and alfalfa-grass stands, the content of crude protein and protein from the introduction of nitrogen changed to a lesser extent – for the introduction of N_{60} on the background of $P_{60}K_{90}$ on average, for all mowing in the dry weight of feed, the content of crude protein increased from 16.9-18.1 to 17.4-19.1%, protein from 12.4-13.3 to 13.0-13.7%. Simultaneously with the increase in the content of crude protein (by 0.5-2.9%), a decrease in the content of nitrogen-free extractives was observed.

Consequently, the inclusion of alfalfa in grass stands provided an increase in the crude protein content to a greater extent than the introduction of nitrogen at a dose of N_{60} on the same cereal stand on the same background of $P_{60}K_{90}$.

On all studied grass stands the highest quality of forage was provided by the introduction of $N_{60}P_{60}K_{90}$+ Fumar. On alfalfa and alfalfa-grass stands, such a combination of technological measures provided the accumulation of 18.4-19.9% of crude protein in dry weight, which is 1.8-2.4% more compared to the variant without fertilisation. Under such conditions, the grass stand accumulated 15.3% crude protein, which is 4.2% more than without fertilisers.

The content of crude fat in dry weight was 2.5-3.8%, crude fibre – 25.1-29.9%. These parameters of feed quality did not significantly depend on the studied factors.

Comparison of the chemical composition of the obtained feed with the zootechnical standards of cattle feeding showed that their values mainly corresponded to the established standards, however, some discrepancies were also noted. Thus, the content of crude protein on the sown cereal stands on the background without fertilisers and with the introduction of $P_{60}K_{90}$ was less than average (11.1-11.9% compared to the standard of 14% in dry weight).

When using the obtained grass feed in animal feeding, it is important to evaluate it according to the indicators provided by the current standards of Ukraine for assessing the quality of feed. According to the data obtained, the content of

feed units in the dry weight of different types of grass stands was 73-82%, exchangeable energy – 8.6-9.5 MJ/kg, the provision of one feed unit with digestible protein – 107-174 g (Table 2).

Table 2. Nutritional value, energy intensity of dry mass and provision of fodder unit with digestible protein of meadow grasslands depending on fertilisation, (the average for 2014-2016)

Fertiliser	Content of feed units, %	Exchangeable energy content, MJ/kg	Provision of feed unit with digestible protein, g
Alfalfa			
No fertilisers	81	9.4	151
$P_{60}K_{90}$	82	9.5	154
$N_{60}P_{60}K_{90}$	82	9.5	164
$N_{60}P_{60}K_{90}$ + Fumar	82	9.5	170
Alfalfa + Fescue Grass + Festuca pratensis			
No fertilisers	76	9.0	152
$P_{60}K_{90}$	77	9.1	155
$N_{60}P_{60}K_{90}$	76	9.2	160
$N_{60}P_{60}K_{90}$ + Fumar	77	9.2	167
Alfalfa + Fescue Grass + Dactylis glomerata			
No fertilisers	76	9.0	155
$P_{60}K_{90}$	78	9.1	152
$N_{60}P_{60}K_{90}$	77	9.2	165
$N_{60}P_{60}K_{90}$ + Fumar	77	9.2	168
Alfalfa + Bromus inermis + Lolium perenne			
No fertilisers	76	8.9	158
$P_{60}K_{90}$	77	9.1	158
$N_{60}P_{60}K_{90}$	78	9.1	168
$N_{60}P_{60}K_{90}$ + Fumar	77	9.2	174
Alfalfa + Bromus inermis + Fescue Grass			
No fertilisers	76	9.0	156
$P_{60}K_{90}$	77	9.1	158
$N_{60}P_{60}K_{90}$	76	9.2	172
$N_{60}P_{60}K_{90}$ + Fumar	77	9.2	173
Bromus inermis + Fescue Grass (grass stand)			
No fertilisers	73	8.6	107
$P_{60}K_{90}$	74	8.7	112
$N_{60}P_{60}K_{90}$	75	8.8	138
$N_{60}P_{60}K_{90}$ + Fumar	75	8.8	143
Zootechnical standard	70-100	8-11	110-115

It was found that the introduction of alfalfa in the composition of alfalfa-cereal grass mixtures contributed to an increase in the content of feed units in the dry weight of grass from 73-75 to 76-78%, and the content of metabolisable energy – from 8.6-8.8 to 8.9-9.2 MJ/kg compared to pure cereal crops.

Comparing the obtained values of these indicators on alfalfa-cereal grass stands with single-species alfalfa sowing, it was determined that alfalfa sowing is characterised by slightly higher nutritional value and energy intensity. Its dry weight contained 4-6% more feed units and 0.3-0.5 MJ/kg more metabolisable energy. The parameters of nutrition and energy intensity changed little under the influence of fertiliser, only a tendency to increase the parameters of these indicators was noted.

The provision of a feed unit with digestible protein in the conducted studies was quite high and depending on the action of the studied factors was 107-174 g. This indicator was most affected by symbiotic and mineral nitrogen. With the inclusion of alfalfa in cereal grass stands, and in pure alfalfa crops in the absence of nitrogen mineral fertiliser, the provision of a feed unit with digestible protein increased from 107-112 g to 151-174 g or by 44-62 g, with the introduction of mineral nitrogen – from 138-143 g to 160-174 g or by 22-31 g. Among legume-grass mixtures, no significant difference was observed in the provision of digestible protein per feed unit.

The application of nitrogen fertilisers improved the supply of digestible protein to the feed unit more significantly on cereal grasses than on alfalfa and alfalfa-cereal grass stands. Nitrogen fertilizers at the rate of N_{60} on the background of $P_{60}K_{90}$ on the cereal grass increased the provision of a feed unit with digestible protein by 26 g, on alfalfa and alfalfa-cereal grass – by 5-14 g.

The highest nutritional value of feed for this indicator on all grass stands was seen with the introduction of $N_{60}P_{60}K_{90}$ + Fumar and amounted to 167-174 g on alfalfa and alfalfa-grass stands (exceeding 13-19 g before the control), 143 g on cereal stands (the increase to the control was 36 g).

CONCLUSIONS

Cultivation of alfalfa and alfalfa-grass stands without nitrogen fertilisers results in the production of grass fodder with a crude protein content in dry weight of 11.1-19.1%. The introduction of alfalfa into grass stands promotes the growth of protein and crude fat in the feed and reduces the content of nitrogen-free extractives.

The chemical composition of grass feed is most affected by nitrogen fertilisers on grass stands. With the introduction of N_{60} on the background of $P_{60}K_{90}$ in the dry mass of feed, the content of crude protein increases by 2.8% and the supply of digestible protein to the feed unit increases by 26 g.

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Вплив удобрення на поживну цінність люцерно-злакових травосумішок у Правобережному Лісостепу

Анотація. Одним із шляхів зменшення дефіциту протеїну та виробництва повноцінних кормів є вирощування люцерно-злакових травосумішок, які завдяки оптимальному співвідношенню білкових і вуглеводних сполук, мінеральних солей та інших цінних біологічно активних речовин найбільш повно задовольняють фізіологічні потреби тварин. Метою досліджень було визначення впливу мінеральних добрив на поживність люцерно-злакових травосумішок. Експериментальні дослідження проводили протягом 2014-2016 рр. на дослідному полі кафедри кормовиробництва, меліорації та метеорології, яке розташоване у ВП НУБіП України «Агрономічна дослідна станція» на чорноземі типовому малогумусному. Результати проведених досліджень показали, що включення люцерни в злакові травостої підвищує вміст сирого протеїну в більшій мірі, ніж внесення азоту в нормі N_{60} на тому ж злаковому травостої на тому ж фоні $P_{60}K_{90}$. Істотних відмінностей у накопиченні сирого протеїну між люцерно-злаковими травостоями з різним складом злакових компонентів на однакових фонах не виявлено. Введення люцерни в травостої сприяє зростанню вмісту протеїну і сирого жиру в кормі та зменшує вміст безазотистих екстрактивних речовин. На хімічний склад трав›яного корму найбільше впливають азотні добрива на травостоях. При внесенні N_{60} на фоні $P_{60}K_{90}$ у сухій масі корму збільшується на 2,8% вміст сирого протеїну і на 26 г забезпеченість кормової одиниці перетравним протеїном. Перетравність сухої маси люцерно-злакових і бобово-злакових травостоїв відносно чисто злакових підвищується на 2-5%. Склад злакових компонентів у бобово-злакових травосумішках та система удобрення суттєво не впливають на перетравність корму. На всіх досліджуваних травостоях найвищу якість корму забезпечує внесення $N_{60}P_{60}K_{90}$+ Фумар

Ключові слова: люцерно-злакові травосумішки, поживність корму, сирий протеїн, сирий жир, обмінна енергія

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Influence of Farming and Tillage Systems on Available Moisture Reserves of Common Chernozem for Spring Wheat Cultivation

Abstract. Numerous studies by Ukrainian and foreign scientists have proven that one of the limiting factors for obtaining stable crop yields is the reserves of productive moisture in the soil, especially during critical periods of their growth and development. The article presents the results of research on the influence of three farming systems – industrial (control), organic and biological and four variants of basic tillage – ploughing by 20-22 cm (control), chiselling by 20-22 cm, disking by 10-12 cm, disking by 6-8 cm on the reserves of productive moisture in the soil for growing spring durum wheat. The results of the research revealed that the highest moisture reserves in the meter thickness of the soil during the sowing period were obtained by combining the biological system of agriculture and chisel tillage, which made it possible to accumulate 199.1 mm in 2018, 179.6 mm in 2019 and 159.9 mm in 2020 of available moisture in the soil. The use of chisel cultivation in combination with industrial and organic

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farming systems also proved to be beneficial in all years of observation over combinations of ploughing and both variants of disking with these systems. During the growing season in all studied farming systems, no-till farming (chiselling and disking) provided the highest reserves of available moisture in the soil. However, the combination of an organic farming system with 20-22 cm chiselling should be considered the optimal option, which provided 74.0 mm of moisture for the flowering period in 2018, 93.7 and 90.9 mm in 2019 and 90.9 mm in 2020, and during the harvesting period, these figures were 61.0, 67.7 and 61.6 mm, respectively. The yield of spring durum wheat grain in this variant was essentially the highest in the experiment and amounted to 4.6, 6.7 and 5.6 t/ha, respectively

Keywords: industrial, organic and biological systems of agriculture, ploughing, chiselling, disking, hydrothermal coefficient, reserves of available moisture in the soil, yield

RELEVANCE

Scientific and practical experience has established that obtaining stable, high, economically and energetically feasible yields of any agricultural crop with a minimal negative impact on the environment is possible only with the introduction of modern farming systems (Tanchyk S.P., Pavlov O.S., 2013; Artyomov M.P., 2013). One of the central links of any farming system is soil cultivation, the role of which, especially in organic farming, is extremely important in ensuring optimal soil fertility and conditions for plant growth and development (Medvedev V.V. *et al.*, 2019; Tanchyk S.P. *et al.*, 2009).

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Scientists have found that in the Right-Bank Forest-Steppe zone, the lack of productive moisture in the soil during critical periods for spring early grain crops causes a decrease in their yield in certain years by 30-50% (Sayko, 2011; Ivashchenko, Rudyk-Ivashchenko, 2011; Tsytsyura, 2017). At present, there has been a gradual decrease in the average annual amount of precipitation for the May-August period, which suggests that the Right-Bank Forest-Steppe is a risky farming zone. Under these conditions, an important aspect is the ability to manage the reserves of available moisture in the soil (Korniychuk, Voronetskaya, 2021).

According to the research of domestic and foreign scientists, the most effective way to preserve and accumulate moisture in the soil is to improve such units of farming systems as tillage, crop rotation system, fertiliser system (Tsylyurik, 2015). In particular, the research of Halvorson *et al.* indicates the undeniable advantage of minimum tillage in terms of the impact on soil moisture reserves and water use efficiency of spring wheat (Halvorson *et al.*, 2019). According to (Johnson *et al.*, 2016; Obalum *et al.*, 2011) surface residues under minimum and conservation tillage can improve soil water and physical properties, conserve soil moisture and increase water use efficiency.

Purpose of the study. Establishment of patterns of formation of productive moisture reserves in typical chernozem depending on farming systems and soil cultivation in spring wheat crops of the Right-Bank Forest-Steppe of Ukraine.

MATERIALS AND METHODS

The research was conducted during 2018-2020 within the stationary two-factor experiment of the Department of Agriculture and Herbology of the Agronomic Experimental Station of the

National University of Life and Environmental Sciences of Ukraine, Pshenychne village, Vasylkiv district, Kyiv region.

In the stationary experiment, three variants of the farming system (factor A) and four variants of the main tillage system (factor B) were studied in a short-term rotation of grain-plough crop rotation with the following sequence of crops: soybeans – winter wheat – sunflower – spring wheat – corn for grain.

The content of gradations of the first factor (A) of agricultural systems is compiled on the basis of their resource provision for extended reproduction of soil fertility. The control variant of agricultural systems is the model of industrial agriculture in which the resource support for the programmable productivity of arable land is the application of 12 tons of organic (manure) and 300 kg of the active substance of mineral fertilisers per hectare in crop rotation ($N_{92}P_{100}K_{108}$), including for spring wheat 290 kg/ha of the active substance ($N_{90}P_{90}K_{100}$) and intensive use of recommended pesticides. Sunflower and corn were manured at the rate of 30 t/ha. The index of ecologisation in such a farming system is 25 (300/12), which is evidence of its industrial nature.

The models of organic and biological farming were compared with the control variant. In the case of organic farming, to ensure programmable productivity, 24 t/ha of organic and 150 kg/ha of NPK mineral fertilisers in active substance ($N_{47}P_{78}K_{25}$), in particular, 130 kg/ha of the active substance ($N_{50}P_{20}K_{60}$) for spring wheat. The use of organic fertilisers in crop rotation under this system involved the application of 12 tons of manure per hectare of crop rotation area and 12 t/ha of green manure (white mustard), which were sown after harvesting winter and spring wheat. The application of pesticides in this system is ecologically justified by the criterion of the ecological and economic threshold of the number of pests. The index of greening agriculture is 6.2 (150/24).

In biological farming, only 24 t/ha of organic fertilisers were used in crop rotation – 12 tons per hectare of manure and 12 t/ha of green manure (white mustard), which were sown after harvesting winter and spring wheat. The index of greening agriculture in this version of the system is 0 (0/24).

Models of farming systems in the stationary experiment by the method of split plots include four variants of basic tillage (factor B) for spring wheat:

1) ploughing by 20-22 cm (control);
2) chiselling by 20-22 cm;
3) disking by 10-12 cm;
4) disking by 6-8 cm.

The experiment was based on the split-section method. The plots on which the variants of basic tillage are implemented have a sown area of 280 m^2 (8 × 35 m), and an accounting area – 225 m^2 (7 × 32.1 m). The plots on which the relevant fertiliser and plant protection systems characteristic of certain variants of the farming system are applied have a sown area of 93.6 m^2 (8 × 11.7 m), and the accounting area is 75 m^2 (7 × 10.7 m). The number of repetitions in the experiment is 4. Sowing of spring wheat durum variety Diana was carried out at the onset of physical ripeness of the soil at a temperature of the sowing layer of 2-3°C.

Soil samples to determine the total reserves and available moisture in the soil were taken with a drill from the layers 0-10, 10-20, 20-30, 30-50, 50-70, 70-100 cm before sowing spring wheat, in the flowering phase of the crop and before harvesting (Tanchyk *et al.*, 2013). Grain yield accounting of the crop was carried out in the phase of full ripeness of spring wheat by continuous harvesting from the accounting areas with bringing to 100% purity and standard humidity of each variant in all repetitions separately.

Sowing of spring wheat durum variety Diana was carried out at the onset of physical ripeness of the soil at a temperature of the sowing layer of 2-3°C. During the years of research, this period fell on the end of March – the first decade of April. The seeding rate was 6 million germinating seeds per 1 ha, the seeding depth – 3-4 cm, and row spacing was 15 cm.

Statistical analysis of experimental data was – performed using Excel from MS Office 365 and Statistica 10 software.

RESULTS

The regime of moisture supply of crops depends primarily on the weather conditions in the years of research. For spring durum wheat, it is important to have a sufficient supply of productive moisture during the sowing period, which is formed mainly due to winter precipitation. This crop requires slightly more available moisture for seed germination and seedlings compared to other early spring cereals. To assess the impact of weather conditions on the reserves of available moisture in the soil, an indicator of the hydrothermal coefficient, which indicates the level of moisture in the territory, is analysed. The adequacy of the HTC with respect to long-term data was assessed by the adequacy indicator (K_i). According to the scale, optimal deviations are those with the coefficient of the significance of deviations in the range of 0 ÷ ± 0.3; tendentially overestimated with K_i in the range of +0.4-1; tendentially reduced – K_i in the range of -0.4-1; significantly overestimated – K_i in the range of +1-2; significantly reduced – K_i in the range of -1-2; extremely overestimated with K_i > +2 and extremely reduced with K_i > -2.

The data in Figure and Table 1 show that the years of the research differed in monthly HTC values. The beginning of the growing season of 2018 was characterised by unfavourable moisture conditions. In particular, in April of this year, the HTC was 0.2, thus characterizing the area as desert, which is a significant deviation from the long-term average (K_i = -1.3), and May with HTC of 0.7 was very dry, which tended to differ from the long-term average (K_i = -0.5). Instead, June and July of this year with HTC indicators of 1.8 and 1.4, respectively, can be attributed to excessively and sufficiently moist months. The month of August can be regarded as unfavourable in terms of moisture (HTC = 0.3), and September with HTC = 1.2 was typical (K_i = -0.1).

Spring 2019 was radically different from the previous year, as April and May with values of 3.1 and 1.9, respectively, were excessively moist, which is not typical for these months (K_i = 1.7 and 0.8). June and August of this year with HTC indicators of 0.98 and 0.73 were dry, which is typical for this period (K_i = -0.2). July with the HTC index of 1.2 was one of the slightly drier months, although it was tendentially more favourable in terms of moisture compared to the long-term average (K_i = 0.8). Thus, 2019 was characterised by waterlogged spring months and rather limited moisture in the rest of the growing season (see Table 1, Fig. 1).

Table 1. The adequacy ratio of the HTC indicator to the long-term average (Ki)

Year of research	Months of the vegetation period						Over the vegetation period
	April	May	June	July	August	September	
2018	-1.3	-0.5	0.7	1.2	-0.7	-0.1	-0.3
2019	1.7	0.8	-0.2	0.8	-0.2	-0.6	0.35
2020	1.0	2.0	-0.4	-0.3	-0.5	-0.5	0.05

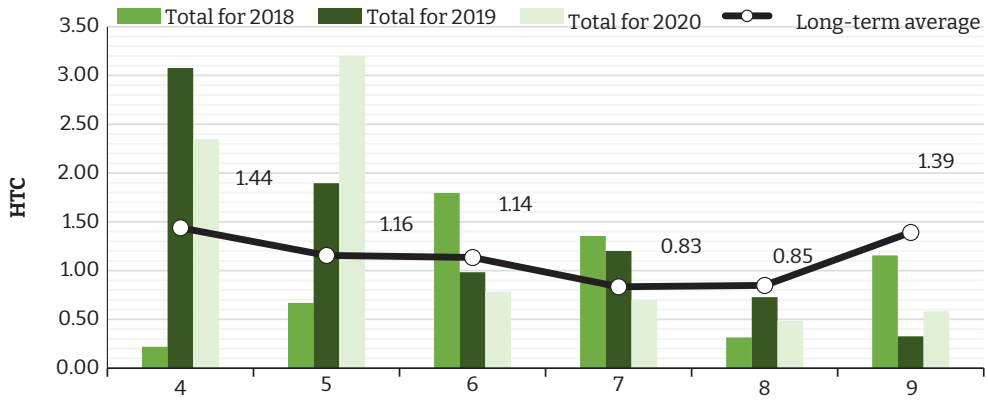

Figure 1. Monthly distribution of HTC, 2018-2020

The vegetation period of 2020 was similar to 2019 in terms of monthly HTC index distribution. April and May of this year were excessively moist with HTC indicators of 2.35 and 3.2, respectively, which is a significant and extreme deviation from the average long-term indicators (K_i = 0.9 and 2.0). The rest of the months in the vegetation period varied from dry June (HTC 0.78) to very dry July, August and September (HTC 0.7, 0.48, 0.58, respectively), while the aridity of this period was confirmed statistically (K_i = -0.3, -0.5 and -0.5).

Thus, the years of research were different in terms of annual HTC indices. However, it is worth highlighting some of their common features: a tendency or extreme increase in GDD (>10°C) of the growing season against the background of typical precipitation; a variegated pattern of the main weather parameters by months of the growing season (see Fig., Table 1).

The data in Table 2 indicate sufficient reserves of available moisture in the soil for the period of sowing spring wheat – 176.9 mm in the spring of 2018, 164.6 – 2019 and 146.3 mm – 2020 on average in the experiment. At the same time, moisture reserves were closely related to the amount of precipitation during the autumn-winter period. Thus, in the autumn and winter months of 2017-2018, there was 465 mm of precipitation, in 2018-2019 – 285 mm and in 2019-2020 – 174 mm. The correlation coefficient between the early spring reserves of available moisture and the amount of precipitation in these periods was r = 0.97.

However, despite the impact of precipitation, the studied factors – cropping systems and basic tillage systems – had an effect on the indicators of available moisture in the soil. Results of the impact of farming systems on the reserves of available moisture revealed the prevalence of biological farming system in all years of determination. In particular, in 2018 the advantage of this variant over the control was 9.4 mm, in 2019 – 2.8, in 2020 – 4.7 mm, which is statistically significant (Table 2).

The effect of cultivation on the accumulation of available moisture in the soil was also significant. No-till cultivation systems – chiselling at 20-22 cm, disking at 10-12 cm and disking at 6-8 cm – created better conditions for better moisture accumulation. Chiselling can be considered the most effective solution, as it provides a significant increase in productive moisture reserves at the time of sowing spring wheat in the range of 10.6-20.1 mm depending on the year. Variants with disking also had a positive effect against the control, but it was significantly lower than chiselling (Table 2).

Table 2. The reserves of available moisture in the meter thickness of the soil depending on the studied factors

Agricultural systems (A)	Basic tillage systems (B)	Moisture reserves, mm								
		before sowing			flowering			before harvesting		
		2018	2019	2020	2018	2019	2020	2018	2019	2020
I (St)	P (St)	150.4	158.3	133.0	70.8	72.6	70.4	57.2	63.4	57.7
	C	188.0	169.6	151.0	71.9	73.7	71.5	58.1	64.5	58.7
	D 1	174.4	157.4	140.1	73.4	75.2	73.0	60.7	67.3	61.3
	D 2	181.2	163.5	149.0	72.3	74.1	71.9	58.1	64.5	58.7
O	P (St)	175.1	167.5	140.7	71.7	81.7	79.2	59.3	65.8	59.8
	C	176.7	169.0	150.5	74.0	93.7	90.9	61.0	67.7	61.6
	D 1	175.2	167.5	149.2	75.1	95.1	92.2	62.4	69.2	63.0
	D 2	170.0	162.6	149.6	73.4	93.0	90.2	63.0	69.9	63.6
B	P (St)	178.0	160.6	134.9	72.2	82.2	79.8	55.1	61.1	61.1
	C	199.1	179.6	159.9	74.8	94.7	89.0	56.6	62.8	63.8
	D 1	182.8	164.9	146.9	73.6	93.2	90.4	56.5	62.8	63.8
	D 2	171.6	154.8	150.4	74.7	94.6	91.8	53.7	59.6	62.0
LSD_{05} (AB)		**4.3**	**4.1**	**5.9**	**1.9**	**2.1**	**2.2**	**2.9**	**3.2**	**2.8**
On average for agricultural systems (a)										
I		173.5	162.2	143.3	72.1	73.9	71.7	58.5	64.9	59.1
O		174.3	166.7	147.5	73.6	90.9	88.1	61.4	68.1	62.0
B		182.9	165.0	148.0	73.8	91.2	87.7	55.5	61.6	62.7
LSD_{05} (A)		**2.2**	**2.0**	**3.0**	**0.9**	**1.1**	**1.1**	**1.4**	**1.6**	**1.4**
On average for basic tillage systems (B)										
P		167.8	162.1	136.2	71.6	78.8	76.5	57.2	63.4	59.6
C		187.9	172.7	153.8	73.6	87.4	83.8	58.6	65.0	61.4
D 1		177.5	163.3	145.4	74.0	87.8	85.2	59.9	66.4	62.7
D 2		174.3	160.3	149.6	73.5	87.2	84.6	58.3	64.7	61.4
LSD_{05} (B)		**2.5**	**2.4**	**3.4**	**1.1**	**1.2**	**1.3**	**1.7**	**1.8**	**1.6**

Note: I – industrial, O – organic and B – biological farming systems; O – ploughing by 20-22 cm, C – chiselling by 20-22 cm, D 1 – disking by 10-12 cm, D 2 – disking by 6-8 cm

Assessment of the effect of the interaction of factors pointed to the significantly highest moisture reserves for the period of sowing the crop for the combination of the biological system and chisel tillage, which allowed to accumulate in 2018 199.1 mm, 2019 – 179.6 and 2020 – 159.9 mm of available moisture in the soil. The use of chisel cultivation in combination with industrial and organic farming systems also prevailed in all years of observation over combinations of ploughing and both variants of discussions with these systems.

During the vegetation period, the moisture available in the soil is used both for the needs of the crop itself and for physical evaporation from the soil. Assessment of the reserves of productive moisture in the soil during the flowering period of the crop reveals that two years with significant moisture in April and May (2019 and 2020) had a substantial advantage in this parameter in organic and biological farming systems. Thus, in 2019, these systems showed productive moisture reserves in the soil of 90.9 and 91.2 mm, respectively, which is significantly higher than the

industrial one – 73.9 mm. In 2020, organic and biological farming provided 88.1 and 88.7 mm, and industrial – 71.7 mm. In 2018, following the dry spring, the efficiency of these systems was levelled, the moisture reserves in the meter layer of soil were 72.1 mm for industrial, 73.6 – for organic, 73.8 mm – for biological systems. Thus, these data indicate that the resource content of organic and biological farming systems provides more efficient accumulation and preservation of soil moisture in the soil due to precipitation in the spring.

The impact of tillage during the flowering period of spring wheat was manifested in a significant benefit of no-till options over ploughing in all years of observation. However, there were no significant differences betweechisellingng and disking variants (Table 2).

At the time of harvesting in certain years (2018, 2019), the reserves of available moisture in the soil under the biological farming system were significantly lower than in the industrial and organic systems, which, most likely, was caused by the early, compared to other options, termination of plant vegetation and increased physical evaporation of moisture from the soil.

The trends for higher moisture reserves in the soil under no-till variants of basic tillage persisted, although the influence of this factor on the time of harvesting was less significant than in the early spring period and flowering of the crop.

Statistical processing of data on spring wheat yield indicates a significant impact of the studied factors on this indicator. On average, for three years of research under the organic farming system, the crop yield was 5.0 t/ha, which is 5.8% higher than the control. Under biological farming, there was a significant decrease in yield, which averaged 44.1% over the years of research. At the same time, this decrease in 2019 and 2020 was more significant – 48.6 and 46.3%, in contrast to 2018, where the yield under this system decreased by 33.2%. In years with excessive moisture in the spring months, such a decrease in spring wheat yield can be associated with a higher degree of weed infestation and pathogen development (Table 3).

Table 3. The yield of spring wheat depending on farming systems and basic tillage, t/ha

Agricultural systems (A)	Basic tillage systems (B)	Yield, t/ha			
		2018	2019	2020	On average over 3 years
I (St)	P (St)	3.4	6.4	5.3	5.1
	C	4.1	6.2	5.5	5.3
	D 1	3.3	5.6	4.9	4.6
	D 2	2.9	5.1	4.3	4.1
O	P (St)	3.7	6.5	5.5	5.2
	C	4.6	6.7	5.6	5.6
	D 1	3.4	6.1	5.1	4.8
	D 2	3.1	5.6	4.6	4.4

Table 3, Continued

Agricultural systems (A)	Basic tillage systems (B)	Yield, t/ha			
		2018	2019	2020	On average over 3 years
B	P (St)	2.3	3.3	2.8	2.8
	C	2.8	3.5	2.9	3.1
	D 1	2.3	2.9	2.7	2.6
	D 2	1.8	2.4	2.4	2.2
LSD_{05} (AB)		**0.22**	**0.28**	**0.25**	**0.25**
On average for agricultural systems (A)					
I		3.4	5.8	5.0	4.8
O		3.7	6.2	5.2	5.0
B		2.3	3.0	2.7	2.7
LSD_{05} (A)		**0.11**	**0.14**	**0.12**	**0.13**
On average for basic tillage systems (B)					
P		3.6	5.4	4.5	4.4
C		3.8	5.5	4.7	4.6
D 1		3.0	4.8	4.2	4.0
D 2		2.6	4.4	3.8	3.6
LSD_{05} (B)		**0.13**	**0.16**	**0.14**	**0.14**

Among the variants of the second factor, the highest yield of spring wheat was obtained under chisel cultivation, which is by 0.2 t/ha (6.6%) more than the control. In the variant with disking by 10-12 cm, the crop yield was 7.7% lower than the control. Reducing the disking depth to 6-8 cm led to a decrease in yield by 18.4% compared to the control.

Among the variants combining factors, the highest yield in the experiment on average for all years of observation was obtained for the combination of organic farming system with the variant of chisel tillage by 20-22 cm – 5.6 t/ha, which significantly exceeds the control.

CONCLUSIONS

The introduction of the organic farming system in the Right-Bank Forest-Steppe zone of Ukraine in combination with the chisel version of the main tillage by 20-22 cm made it possible to form high reserves of productive moisture in the soil for the period of sowing spring wheat, which in 2018 amounted to 176.7 mm, 2019 – 169.0 and 2020 – 150.5 mm, which is significantly higher than the control. At the same time, this variant was more advantageous in terms of moisture supply during the entire growing season of the crop, which allowed to form the highest yield of spring wheat in the experiment at the level of 5.6 t/ha on average over three years.

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Вплив систем землеробства та обробітку ґрунту на запаси доступної вологи чорнозему звичайного за вирощування пшениці ярої

Анотація. Численними дослідженнями українських і зарубіжних вчених доведено, що одним із лімітуючих факторів отримання стабільних урожаїв сільськогосподарських культур є запаси продуктивної вологи в ґрунті, особливо в критичні періоди їх росту і розвитку. У статті наведено результати досліджень впливу трьох систем землеробства - індустріальної (контроль), органічної та біологічної та чотирьох варіантів основного обробітку ґрунту - оранки на 20-22 см (контроль), чизелювання на 20-22 см, дискування на 10-12 см, дискування на 6-8 см на запаси продуктивної вологи в ґрунті за вирощування пшениці твердої ярої. Результати досліджень показали, що найвищі запаси вологи в метровій товщі ґрунту на період сівби отримано за поєднання біологічної системи землеробства та чизельного обробітку, що дало змогу накопичити 199,1 мм у 2018 р., 179,6 мм у 2019 р. та 159,9 мм у 2020 р. доступної вологи в ґрунті. Застосування чизельного обробітку в поєднанні з індустріальною та органічною системами землеробства також виявилося переважним у всі роки спостережень над поєднаннями оранки та обома варіантами дискування з цими системами. Протягом вегетаційного періоду в усіх досліджуваних системах землеробства нульовий обробіток (чизелювання та дискування) забезпечував найвищі запаси доступної вологи в ґрунті. Проте оптимальним варіантом слід вважати поєднання органічної системи землеробства з чизелюванням на 20-22 см, яке забезпечило на період цвітіння 74,0 мм вологи у 2018 році, 93,7 і 90,9 мм у 2019 році та 90,9 мм у 2020 році, а на період збирання врожаю ці показники становили 61,0, 67,7 і 61,6 мм відповідно. Урожайність зерна пшениці твердої ярої в цьому варіанті була практично найвищою в досліді і становила 4,6, 6,7 та 5,6 т/га відповідно

Ключові слова: індустріальна, органічна та біологічна системи землеробства, оранка, чизелювання, дискування, гідротермічний коефіцієнт, запаси доступної вологи в ґрунті, урожайність

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Winter Wheat Yields Depending on Preceding Crops in the Right-Bank Forest-Steppe of Ukraine

Abstract. The article presents the results of research on the specifics of winter wheat yield formation depending on preceding crops. It was established that in the Right-Bank Forest-Steppe, according to the ability to provide winter wheat during the sowing period (0-10 cm soil layer) with available moisture, the preceding crops were arranged as follows: peas – winter rape – sunflower – soybeans – corn for silage. At the time of sowing winter wheat, sufficient reserves of available moisture in the 0-10 cm soil layer were established after peas and winter rape, respectively, 11.5 and 10.9 mm. Soybeans and corn for silage, as predecessors, did not provide sufficient moisture reserves for sowing winter wheat in both the 0-10 cm and 0-30 cm soil layers. The highest yield of winter wheat in 2019-2021 averaged 5.68 t/ha, achieved by planting it after peas. The use of winter rape and soybeans as a precursor reduced its yield by 4.40 and 5.40%, respectively, which in absolute terms amounted to 0.25 and 0.31 t/ha. When winter wheat was cultivated after corn for silage and sunflower, the crop yield decreased by 0.48 and 0.67 t/ha, respectively. The highest quality indices of winter wheat grain – protein content of 13.1 and 13.3% and gluten content of 25.2 and 25.5% – were obtained when it was placed after legumes (peas and soybeans). Winter rape, as a predecessor, provided grain quality indices of 13.0% protein and 24.5%

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gluten. When sown after sunflower and corn for silage, the protein content of winter wheat grain was 12.6% and 12.8%, respectively, and the gluten content was 24.0% and 24.1%

Keywords: winter wheat, predecessor, available moisture reserves, yield

RELEVANCE

The current state of Ukraine's economy demonstrates that the share of agricultural production in its structure is 15-18%, and in the case of state support, it can increase to 25% (Kernes, 2020; Marenych M *et al.*, 2020). The main task of agricultural production is ensuring the food security of the state, which depends to a large extent on the level and growth rate of grain production (Yermolaev *et al.*, 2011; Tanchyk & Babenko, 2015; Petrychenko & Korniychuk, 2018). Winter wheat is ranked among the most valuable grain crops in terms of its high food value. In global agriculture, it is one of the three strategically important agri-food crops (wheat, rice, and corn). Therefore, global food security depends on the state of development of wheat production (Kernes, 2020). The potential of modern adaptive technologies for growing winter wheat is 30-50% increase in its yield from the current level. However, the main obstacle to the growth of wheat production may be climate change, which will result in a deterioration in the moisture supply. Given that moisture reserves determine the agrochemical, agrophysical and biological properties of the soil, they are crucial for plant growth and development, as well as the formation of crop structure elements. One of the determining factors in the formation of the water regime of the soil in winter wheat crops is the optimisation of its placement in crop rotation after various predecessors. The relevance of this issue determined the chosen research topic.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Achieving the potential productivity level of modern varieties is possible by optimising the placement of crops in the crop rotation after the best preceding crop. This is determined by a number of factors, including the quantity and quality of plant residues left by the crop on the field, the type of root system and its penetration depth, water consumption, impact on phytosanitary conditions, harvesting time, etc. The issue of forming optimal reserves of available moisture in the soil, both at the time of sowing and during the growing season, is particularly acute in the context of climate change (Yeshchenko, 2014; Gamayunova *et al.*, 2016; Panfilova *et al.*, 2019; Petrychenko *et al.*, 2021).

The productivity of winter wheat reaches 50-60% in the autumn period, during which it is important to provide the crop with all the necessary vital factors (moisture, nutrients, heat) in the optimal amount and optimal proportions, which largely depends on the preceding crop (Davydenko, 2012; Tanchyk *et al.*, 2015; Gamayunova *et al.*, 2016). Therefore, sowing after the best preceding crops, namely clean (low moisture zone) and occupied fallow (perennial legumes on one mowing, peas, vetch-oat mixtures) is crucial for the placement of winter cereals (Buzynnyi, 2015; Gamayunova et al, 2019; Andrii Siroshtan *et al.*, 2021). However, the current structure of sown areas shows that the main areas (approximately 80%) of winter cereals in Ukraine are planted after non-pair crops: soybeans, winter and spring rape, corn for silage, buckwheat, cereals, and sunflower. These crops do not provide optimal conditions for the growth and development of winter wheat, which leads to a decrease in available soil moisture, deterioration of nutritional and phytosanitary conditions, and, as a result, a decrease in yield. Therefore, the issue

of placing winter wheat in the crop rotation after the most effective predecessors is relevant.

The purpose of the research is to identify the impact of preceding crops on the formation of winter wheat productivity in the Right-Bank Forest-Steppe of Ukraine.

MATERIALS AND METHODS

The field research was carried out in a stationary field experiment of the Educational and Scientific Innovation Center of Agrotechnologies of LLC "Agrofirma Kolos" in Pustovarivka, Skvyra district, Kyiv region, during 2019-2021. The studied soil is a typical deep, coarse-dusty, medium loamy chernozem with a humus content of 4.5%, hydrolyzednitrogen–184mg/kg,mobilephosphorus – 233 mg/kg, mobile potassium – 95 mg/kg, pH_{KCl} 6.5, and the number of absorbed bases – 85-99%. By its composition and properties, the soil is perfectly suitable for growing all crops recommended for this zone. The experiment included the study of the influence of predecessors for the cultivation of winter wheat: 1. pea (control); 2. winter rape; 3. soybean; 4. sunflower; 5. corn for silage. The size of the sowing plot was 250 m^2, the accounting plot was 180 m^2, the replication of the experiment was four times, and the location of the plots was randomised. Main tillage for wheat (ploughing to a depth of 20-22 cm). The content of available moisture in the soil was determined by the thermostatic-weight method according to DSTU ISO 16586:2005. The harvest was calculated by direct combine harvesting. Crop quality indices were determined by infrared spectroscopy using an infrared analyser NIR Systems 4500 in accordance with DSTU 4117: 2007 Grain and products of its processing.

RESULTS AND DISCUSSION

One of the main criteria for plant growth and development is sufficient soil moisture. Placing winter wheat after various crops rotation creates unequal conditions for its growth and development, primarily due to the different amounts of moisture they leave behind. The research results revealed that the preceding crops had a significant impact on the soil moisture reserves both at the time of sowing winter wheat and during its vegetation. It was found that at the time of sowing, sufficient moisture reserves in the 0-10 cm soil layer were formed when winter wheat was sown after peas and winter rape, respectively, 11.5 and 10.9 mm (Fig.).

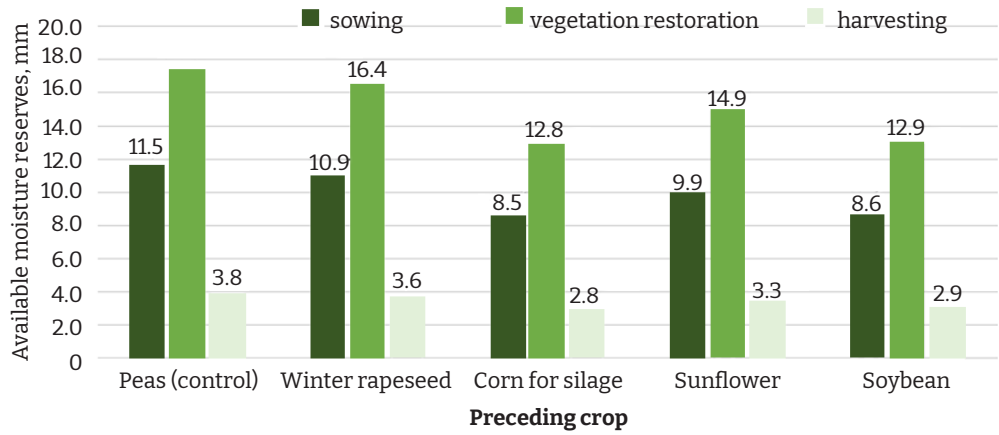

Figure 1. Available moisture reserves in the 0-10 cm soil layer in winter wheat crops depending on the preceding crops in rotation (average for 2019-2021)

Note: LSD_{05} (sowing) = 1.0; LSD_{05} (vegetation restoration) = 1.8; LSD_{05} (harvesting) = 0.8;

It is worth noting that after sunflower, the average moisture reserves in the 0-10 cm soil layer in 2019-2021 were 9.9 mm. And after soybeans and corn for silage, the reserves of available moisture were equivalent and the lowest compared to the studied predecessors, respectively, 8.5 and 8.6 mm. Analysis of the moisture reserves in the one-meter soil layer shows that the difference between the studied preceding crops and the control only increased (Table 1).

Table 1. Available moisture content in the soil by various crops in rotation preceding winter wheat crops, the average for 2019-2021, mm

Preceding Crop	Soil layer, cm	Moisture reserves, mm		
		sowing	restoration of vegetation	harvesting
Peas (control)	0-30	27.4	41.1	9.1
	0-100	150.7	177.8	50.2
Winter rapeseed	0-30	24.8	37.2	8.3
	0-100	94.6	160.8	47.3
Soybean	0-30	21.6	32.4	7.2
	0-100	84.1	155.6	42.1
Sunflower	0-30	25.5	38.3	8.5
	0-100	82.3	152.3	39.2
Corn for silage	0-30	18.2	27.3	6.1
	0-100	88.9	164.5	44.5
LSD_{05} (0-30cm) =		2.4	4.4	1.3
LSD_{05} (0-100cm) =		11.3	18.2	5.0

The highest reserves of available moisture were obtained after peas – 150.7 mm, after rapeseed they were 94.6 mm, and the lowest after sunflower – 82.3 mm, which can be explained by both the harvesting time of the preceding crop and biological characteristics of water consumption. Further monitoring of the available moisture content in the soil shows that even intense autumn and winter precipitation could not compensate for the moisture loss after such predecessors as soybean and sunflower.

In particular, after the winter wheat vegetation resumed, the highest moisture reserves in the one-meter soil layer were observed following peas and corn for silage (177.8 and 164.5 mm, respectively), and the lowest – following soybeans and sunflower (155.6 and 152.3 mm). During the spring and summer vegetation period, moisture reserves decreased by half. The maximum moisture retention in the soil both in the 0-10 cm layer and in the 0-100 cm layer was observed when winter wheat was grown after peas and winter rapeseed.

The yield of a crop is an integral indicator of the performance of its cultivation technology. According to the results of standard studies conducted in 2019-2021 on chernozem, winter wheat yielded the highest after peas (5.68 t/ha) (Fig. 2).

Sowing wheat after winter rape reduced its yield by 4.4%, which in absolute terms amounted to 5.43 t/ha. After soybeans, it amounted to 5.37, and sunflower – 5.20 t/ha. The lowest yield of the crop compared to the control variant (peas) was obtained following corn for silage, where it was 5.01 t/ha.

One of the main indicators of the quality of the product is the protein and gluten content of winter wheat grain. They show the value of the resulting products. It is worth noting that the protein and gluten content of winter wheat grain is not only a genetically determined indicator,

but can also vary depending on growing conditions and technological practices. In particular, the protein content, depending on technological factors, can range from 10-12 to 20-25%.

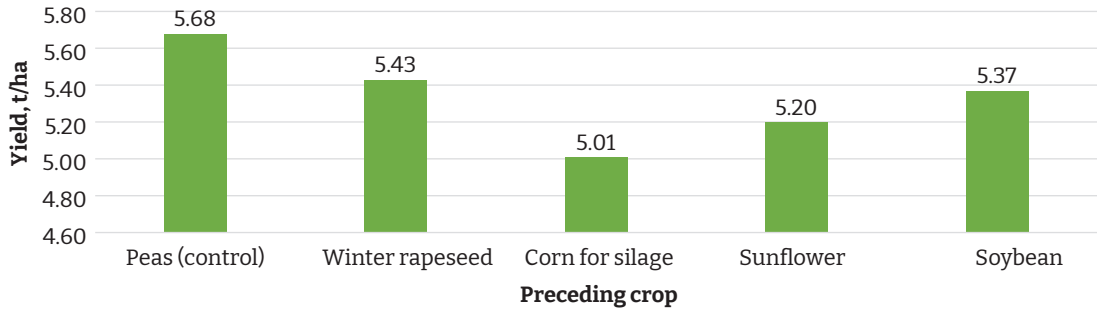

Figure 2. Winter wheat yields depending on preceding crops in rotation (the average for 2019-2021)
Note: LSD_{05} (sowing) = 1.0; LSD_{05} (vegetation restoration) = 1.8; LSD_{05} (harvesting) = 0.8;

The main part of the protein is made up of amino acids, of which lysine, tryptophan, methionine, phenylalanine, leucine, isoleucine, threonine, and valine are essential for humans, as they are not synthesised in the human body and must be supplied with food. It has been established that 400-500 g of wheat bread and bakery products cover about a third of a human's daily food needs, half of the carbohydrate needs, a third (40%) of complete proteins, 50-60% of B vitamins, and 80% of vitamin E. Wheat bread almost completely meets human needs for phosphorus and iron, and 40% of calcium. Based on the analysis, the average protein and gluten content in winter wheat grain varied from 12.6% to 13.3% and from 24.0% to 25.5%, respectively, depending on the predecessor (Fig. 3). The highest protein content (13.3%) of winter wheat grain was achieved through sowing it after peas. Rapeseed and soybeans, as predecessors, had an equivalent effect on the protein content of winter wheat grain (13.0-13.1%). The lowest protein content in winter wheat grain was obtained when placed after sunflower and corn for silage, 12.6% and 12.8%, respectively. In terms of gluten content, the general trend of the influence of precursors continued.

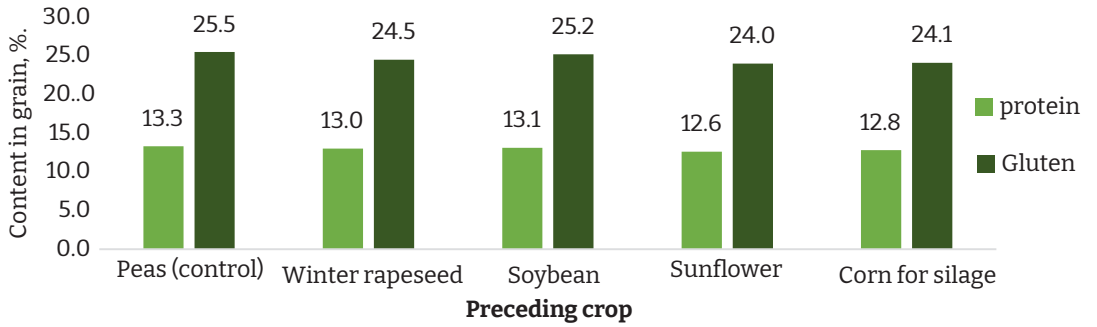

Figure 3. Protein and gluten content in winter wheat grain depending on the preceding crop in rotation (the average for 2019-2021)
Note: LSD_{05} = 0.4 (protein); LSD_{05} = 1.0 (gluten);

CONCLUSIONS

1. During the sowing period of winter wheat, the largest reserves of available moisture in the 0-10 cm soil layer were formed after peas (11.5 mm) and winter rapeseed (10.9 mm). When winter wheat was sown after soybeans and corn for silage, the available moisture reserves were minimal compared to other preceding crops and amounted to 8.6 and 8.5 mm, respectively.

2. In the Right-Bank Forest-Steppe of Ukraine on common chernozems, winter wheat produced the highest yield of 5.43-5.68 t/ha after peas and winter rapeseed. Soybeans, as a predecessor, provided a wheat yield of 5.37 t/ha. When sown after sunflower, the yield of wheat decreased by 8.4% compared to peas, and for corn for silage by 11.8%.

3. The highest values of the protein content of 13.1 and 13.3% and gluten content of 25.2 and 25.5% in winter wheat grain were obtained when sown after legumes (peas and soybeans). Winter rapeseed, as a predecessor, contributed to grain quality indices of 13.0% protein and 24.5% fat. When cultivated after sunflower and corn for silage, the protein content was 12.6% and 12.8%, and the gluten content was 24.0% and 24.1%.

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Урожайність озимої пшениці залежно від попередників у Правобережному Лісостепу України

Анотація. У статті наведено результати досліджень особливостей формування врожайності пшениці озимої залежно від попередників. Встановлено, що в Правобережному Лісостепу за здатністю забезпечувати пшеницю озиму в період сівби (0-10 см шар ґрунту) доступною вологою попередники розташовувалися таким чином: горох – ріпак озимий – соняшник – соя – кукурудза на силос. На момент сівби озимої пшениці достатні запаси доступної вологи в шарі ґрунту 0-10 см встановилися після гороху та озимого ріпаку, відповідно 11,5 та 10,9 мм. Соя та кукурудза на силос, як попередники, не забезпечили достатніх запасів вологи для посіву озимої пшениці як у шарі ґрунту 0-10 см, так і 0-30 см. Найвища врожайність озимої пшениці в 2019-2021 рр. в середньому 5,68 т/га була досягнута за сівби її після гороху. Використання в якості попередника озимого ріпаку та сої знижувало її врожайність на 4,40 та 5,40% відповідно, що в абсолютному вираженні становило 0,25 та 0,31 т/га. При вирощуванні озимої пшениці після кукурудзи на силос та соняшнику врожайність зменшилася на 0,48 та 0,67 т/га відповідно. Найвищі показники якості зерна озимої пшениці - вміст білка 13,1 і 13,3% та клейковини 25,2 і 25,5% – були отримані при розміщенні її після бобових культур (гороху та сої). Озимий ріпак, як попередник, забезпечив показники якості зерна на рівні 13,0% білка та 24,5% клейковини. При розміщенні після соняшнику та кукурудзи на силос вміст білка в зерні озимої пшениці становив 12,6% та 12,8% відповідно, а вміст клейковини - 24,0% та 24,1%

Ключові слова: пшениця озима, попередник, запаси доступної вологи, урожайність

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Features of Changes in the Number and Composition of the Microbiome of the Rhizosphere of Winter Wheat in the Process of Ontogeny

Abstract. In agroecosystems, microorganisms are the main factor in the soil formation process, plant nutrition and phytosanitary condition of the soil. All measures aimed at restoring soil fertility and increasing productivity, environmental safety of agricultural production, are closely related to the activity of microorganisms. Increased local activity, biomass and diversity of microbiota are one of the most important characteristics that distinguish the rhizosphere from the total soil volume. The purpose of the research was to study the number and composition of the microbial complex of the rhizosphere of grain crops (winter wheat of different varieties of domestic selection) in the process of ontogenesis. To conduct a set of microbiological studies, soil samples (typical chernozem) were selected and prepared in compliance with standard requirements for sample preparation and

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storage in laboratory conditions. Analysis of rhizosphere soil samples was carried out on variants of different varieties of winter wheat of domestic selection. The number of soil microorganisms was determined by seeding suspensions on nutrient media according to generally accepted methods in microbiology. The determination of the total microbial biomass in the soil was carried out by the rehydration method, and the intensity of soil "breathing", in terms of CO_2 release and O_2 absorption, was determined by the manometric method (Warburg apparatus). It was found that winter wheat varieties affected the formation of the microbiome of typical chernozem. The number and composition of the microbial complex of the rhizosphere of winter wheat in the process of ontogenesis changes significantly, especially in terms of the ratio of the number of spore-forming and non-spore forms of microorganisms under the same conditions of agricultural technology for growing crops. The rhizosphere's total pool of saprotrophic microorganisms shows biomass variability and changes in favour of ecoplastic bacilli. An increase in the number of spore-forming bacteria to 4.2×10^7 CFU/g was found in the variants of cultivation of certain varieties. Cultivation of different varieties of winter wheat demonstrates stable indicators of CO_2 emission intensity – from 5.2 to 7.0. A similar trend can be traced in the absorption rate of O_2 (no more than 5.3-6.8)

Keywords: soil microorganisms, microbial biomass, varietal specificity, the intensity of CO_2 emission, dynamics of O_2 absorption, spore-forming bacteria

RELEVANCE

The microbiome is multifunctional and participates in soil formation, plant nutrition and determines the phytosanitary status of the soil. Microorganisms respond quickly to changes in environmental conditions and at a good ecological status of the soil is accompanied by restructuring in the microbial cenosis and its functional activity, and at a bad – leads to unpredictable consequences and death of certain groups of microorganisms. While adapting to new conditions of habitat, microbial cenosis shows resistance to them or irreversibly changes its functional properties, which affects soil fertility (Bulyhin, Tonkha, 2019). Agricultural technologies directly or indirectly affect the activity of microorganisms (Patyka, Tonkha *et al.*, 2019; Gadzalo, Patyka, Zarishnyak, 2015; 2019).

The diversity and structure of the bacterial complex in the rhizosphere is highly differentiated depending on the genotype of the plant, the type of soil, the level of agriculture, as well as the characteristics and morphology of the root system of plants (Berg, 2009). Thus, the level of genetic potential that determines the formation of plant-microbial systems, the effectiveness of symbiosis, the availability of nutrients and the likelihood of pathogenic infection depends on the plant variety, the group of rhizosphere microorganisms. The system of controlling the number of microorganisms is commonly known to be dominated by a specific microbiome that competes and exhibits biological activity (for example, antagonistic to plant pathogens). Thus, the ability of spore-forming bacteria of the genus *Bacillus* to neutralise phytopathogenic organisms may also be determined by both the high rate of occupation of their ecological niche in the rhizosphere and the biosynthesis of antibiotic substances and other antifungal metabolites (Olanrewaju, Glick et. al, 2017; Chebotar *et al.*, 2009).

The plant rhizosphere is a unique soil environment, the distinctive feature of which is the constant supply of low molecular weight compounds in the form of root exudates. A large amount of active microbiota is maintained in the rhizosphere, the biomass and polymorphism of which can be higher by several orders of magnitude than in the total arable soil layer.

Long-term experimental material on the diverse importance of soil microorganisms in the ontogeny of higher plants has been accumulated. The rhizosphere of plants is a promising environmental resource for the search for new universal agents of microbial preparations that create a powerful basis for high-tech biotechnological developments for the formation of plant-microbial interactions in agricultural crops. With the further development of comprehensive scientific research, the main focus is on both processes occurring in the rhizosphere and those related to human activity, especially agricultural production (Patyka, Tonkha *et al.*, 2018; 2019). The data on the specific features of changes in the number and composition of the microbiome of the rhizosphere of cereals (winter wheat) in the process of ontogeny should be expanded with regard to the available varieties of winter wheat.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Today, the mechanisms of colonisation of plant organisms by microorganisms and the interaction of bacteria with them, which positively affect the growth and development of the plant, contribute to the process of mineral nutrition, protection against pathogens, etc. have already been established (Moshynets, Kosakivska, 2010). However, the rhizosphere microbe of cultivated plants is still insufficiently studied. At present, studies of the microbiome of the winter wheat rhizosphere, and the properties of the dominant species of soil microorganisms are of particular relevance. It is possible to thoroughly investigate the processes that occur in a particular environment (for example, the activity of mineralisation processes in the presence of spore bacteria or mineralisation of organic compounds, the availability of organic nitrogen, high enzymatic activity, changes in aeration conditions, etc.) Different variants of cereal crop cultivation and their varietal diversity reveal both quantitative differences in the representation of certain types of microorganisms and qualitative changes in the composition of the microbiome.

Increased local activity, biomass and diversity of microbiota are one of the most important characteristics that distinguish the rhizosphere from the total soil volume. The rhizosphere is characterised by a large number of nutrient substrates used by soil bacteria. Soil bacteria are able to competitively colonize plant roots and can be either biofertilisers or antagonists (the basis of microbial preparations) or both. Thus, the diversity of spore bacteria that dominate in agrocenoses directly or indirectly determines the processes of formation of productive biomass of cultivated plants – yield (Mandic-Mulec *et. al*, 2015; Patyka, Bublik et. al, 2015).

The soil prokaryotic complex is mutually beneficial for plants due to various mechanisms of interaction, in particular, through optimisation of nutrient supply to plants, antagonism to other microorganisms, especially pathogens, synthesis of growth regulators or enhancement of secondary metabolic pathways that are directly related to the increase of plant stress resistance (Smirnov, 2001). The study conducted by Gazheeva *et al.* (2011) revealed that the total number of rhizosphere microorganisms actively changes according to the phases of grain crop development (*Triticum aestivum* L., *Hordeum distichon* L., *Avena sativa* L.). There are certain uniform changes for barley, wheat in the tillering stage, where the total number of microorganisms is minimal and further reaches the maximum at the earing stage. The change in the number of bacterial communities of the rhizosphere during the growing season is primarily associated with changes in the composition and quantity of root exudates of plants, which are a source of nutrition for microorganisms.

The population of micromycete forms and their species structure of both rhizosphere and spikelet can correlate with the rate of development

of the corresponding isogenic lines (for example, those determined by the dominant/recessive state of *VRN* genes). Therefore, there is an assumption that genes indirectly, through participation in the regulation of physiological and biochemical processes, can be involved in the formation and functioning of the mycocenosis of soft wheat (Mironovskaya 808 variety).

It is proved that virtually any agrotechnical technique is accompanied by a noticeable and statistically significant change in the structure of microbial communities, which in the future can be used to create new technologies for managing soil fertility and universal approaches for analysing the agroecological state of soils according to metagenomic analysis (Patyka *et al.*, 2016).

Long-term use of high doses of mineral fertilisers suppresses the development of nitrogen-fixing, cellulose-destroying, ammonifying microorganisms, while the activity of mineralisation and denitrification increases, which leads to the loss of soil humus and causes a decrease in its stability (Cerna *et al.*, 2003).

An important characteristic of the rhizosphere microbiome is the ratio of the main physiological groups of microorganisms. Research conducted by G.V. Dobrovolsky, V.P. Patyka, V.V. Volkogon, G.O. Iutynska, D.G. Tikhonenko, V.T. Yemtsev, K.B. Novosad, M.V. Patika and other scientists created the fundamental basis of the modern concept of soil microbiota. Today, the introduction of ecologically oriented t echnologies for growing crops requires a detailed study of the characteristics of the functioning of agrocenoses to establish the regularities of the process of forming the productivity of terrestrial phytocenosis and ensuring the sustainable development of the agricultural sector.

The purpose of the study is to identify the number and composition of the microbial complex of the rhizosphere of grain crops (winter wheat of different varieties of domestic selection) in the process of ontogenesis.

MATERIALS AND METHODS

The research was conducted on the basis of the National University of Life and Environmental Sciences of Ukraine, Prof. Shykula Department of Soil Science and Soil Protection and the separate subdivision of NUBiP of Ukraine "Agronomic Research Station" (Pshenychne, Vasylkiv district, Kyiv oblast), during the spring and summer vegetation of winter wheat (2019-2021). Soil type – typical deep low-humus coarse-dusted medium loam on loess-like loam, most common in the Right-Bank Forest-Steppe of Ukraine. To conduct a set of microbiological studies, soil samples (typical chernozem) were selected and prepared in compliance with standard requirements for sample preparation and storage in laboratory conditions, according to DSTU 4287 : 2004. Soil samples were examined in quadruplicate. Samples of rhizospheric soil were taken from the roots of plants after careful shaking, and in dynamics during the main phases of wheat organogenesis: emergence, earing, flowering and milky ripeness, repeated three times. The number of soil microorganisms was determined by sowing suspensions on nutrient media according to generally accepted methods in microbiology: GCU (Zvyagintseva), meat-peptone agar (MPA) to account for microorganisms that use organic forms of nitrogen; starch-ammonia agar (SAA) – for microorganisms that assimilate mainly nitrogen of mineral compounds; oligonitrophilic microorganisms on Ashby's medium; Chapek's medium and wort agar (WA) – for micromycetes; cellulose-degrading microorganisms – on Hutchinson's medium; in addition, bacteria growing on agarised soil extract (AS) were also taken into account. The degree of dominance of microorganisms above 10.0% was determined morphologically. The total microbial biomass in the soil was determined by the rehydration method (Blagodatsky, Blagodatskaya, Gorbenko, and Panikov, 1987). The intensity of soil "breathing" was de-

termined as per CO_2 release and absorption of O_2 by the manometric method on the Warburg apparatus. Statistical analysis was performed using Statistica 8.0, and the data were calculated using MS Excel.

RESULTS AND DISCUSSION

The data on the number of soil microorganisms under winter wheat indicate the variability of microbial biomass by varietal variants. Thus, the number of spore-forming bacteria increased: in the varieties Trudivnytsia Myronivska, Manera Odeska, Liner, Legend Bilotserkivska and Poliska 90 was twice as high (4.2 x 10^7 CFU/g on average) compared to Mip Valencia, Mip Dnipryanka and other varieties of the Breeding and Genetic Institute of NAAS of Ukraine (2.0 x 10^7 CFU/g soil). This indicates the activation of bacillary forms of microorganisms during the ontogeny of wheat plants (Table 1, 1a).

Table 1. Microbiological analysis of samples taken from the rhizosphere of winter wheat of different varieties of domestic selection (SE NUBiP of Ukraine "Agronomic Research Station", 2019-2020)

Physiological groups m/o /nutrient medium/ quantitative unit	*Winter wheat varieties (Triticum aestivum L.)*									
	Lainer (durum)	Prozoryi (durum)	Shlyakhetnyy (durum)	Namysto	Shchedrivka Kyivska	Poliska 90 (etalon)	Lehenda Bilotserkivska	Lisova pisnya	Muza Bilotserkivska	Zdoba Kyivska
m/o, (SAA), mln CFU/g	10.07± 0.29	10.27± 0.90	15.00± 1.03	10.27± 0.96	15.90± 0.87	11.70± 0.55	15.84± 0.90	11.70± 0.46	16.08± 1.03	12.18± 0.94
m/o, (SAA), mln CFU/g	15.03± 0.72	14.20± 0.37	11.93± 1.01	14.30± 0.41	12.30± 1.06	12.0± 1.02	13.90± 0.74	16.25± 0.88	14.52± 0.78	13.94± 0.75
Micromycetes thousand CFU/g	**52.30±** 1.02	48.5± 0.98	43.5± 1.02	45.8± 0.96	40.1± 0.87	**52.8 ±1.00**	**53.45 ±1.02**	44.6± 0.95	47.3± 0.67	48.6± 0.74
spore bacteria (LB), mln CFU/g	3.72 **±1.03**	2.3± 0.67	1.99± 0.65	1.54± 0.98	1.65± 0.78	**4.20 ±0.98**	**4.0 ±1.06**	2.50± 0.98	1.59± 0.82	1.77± 0.92

Note: m/o – microorganisms; mln CFU/g of soil; (thousand CFU/g of soil);

Table 1a. Microbiological analysis of samples taken from the rhizosphere of winter wheat of different varieties of domestic selection (SE NUBiP of Ukraine "Agronomic Research Station", 2019-2020)

Physiological groups m/o /nutrient medium/ quantitative unit	*Winter wheat varieties (Triticum aestivum L.)*								
	MIP Valenciya	MIP Dnipryanka	Trudovnitsya Myronovska	Myronovska Slava	Veteran	Harantiya Odeska	Manera Odeska	Nyva Odeska	Tradytsiya Odeska
m/o, (SAA), mln CFU/g	15.27± 0.71	14.64± 0.33	16.13± 1.05	13.11± 0.16	20.97± 1.59	14.96± 1.09	16.77± 0.71	9.45± 0.58	8.60± 0.67
m/o, (SAA), mln CFU/g	14.56± 0.87	16.60± 0.98	13.19± 0.94	14.50± 0.78	15.38± 0.76	13.41± 0.79	11.99± 1.02	13.95± 0.74	16.60± 0.63
Micromycetes thousand CFU/g	47.60± 1.05	38.90± 1.20	43.0± 0.98	38.27± 0.95	40.9± 1.02	39.0± 0.93	51.2± 1.08	37.8± 0.88	39.9± 0.91
spore bacteria (LB), mln CFU/g	1.98± 0.68	1.67± 0.78	4.0± 1.05	2.0± 0.65	2.1± 0.86	1.88± 0.92	3.79± 0.82	1.66± 0.66	1.72± 0.83

Note: m/o – microorganisms; mln CFU/g of soil; (thousand CFU/g of soil);

The development of freely existing forms of microorganisms of the genus *Azotobacter* was observed in the rhizosphere of winter wheat varieties. The number of micromycetes by varietal variants ranged from 38,270 to 53,450. CFU/g of soil.

The results of studies of the soil microbiome in the agrocenosis of winter wheat showed a significant differentiation in the number of microorganisms of the main physiological groups depending on the variety of plants (Table 2). The number of oligonitrophilic bacteria in the tilth layer of soil in winter wheat crops during the growing season increased and varied between 169-302 million CFU/g of soil (except for the variant with wheat variety MIP Dnipryanka), which indicates the passage of nitrogen-fixing processes. Nitrogen significantly affects the formation of plant productivity elements. Winter wheat is commonly known to have a long growing season, to bush up heavily in autumn and develop a powerful root system, to resume growth in early spring and assimilate a relatively large amount of nitrogen starting from the beginning of germination to the tube phase 75-90% of its total removal. Thus, the resumption of winter wheat vegetation in spring is accompanied by intensive growth processes, and therefore winter wheat plants are in urgent need of nutrients.

However, due to low temperatures and high soil moisture, which inhibit nitrification, the nitrogen content in the root layer in early spring is usually insufficient, which causes the onset of the first critical period in the nitrogen nutrition of plants in winter wheat. Observations of bacterial biomass (a living and sensitive component of organic matter) under different varieties of winter wheat reveal an increase in this indicator from 6 to 9 t/ha.

It is generally believed that the status of soil microbial communities depends on the farming systems (mineral or organic), and the agrotechnical methods used (fertiliser application, crop cultivation, crop rotation, plant residue management techniques). Thus, the variants of the experiment contain 75-132 million streptomycetes per 1 g. The relative quantity of mushrooms in the variants MIP Dnipryanka, Poliska 90, Namysto and Shchedrivka Kyivska was higher compared to other varietal variants (e.g. Garantiya Odeska, Lisova Pisnya, Trudivnytsya Myronivska, (Table 2).

Table 2. The number and biomass of soil microorganisms for the cultivation of different varieties of *Triticum* (2019-2021)

Variant	Biomass of bacteria, t/ha	Bacteria, on media			Oligonitrophilic bacteria	Micromycetes	Streptomycetes	cellulolytic thous./g of dry soil
		SAA	SAA+WA	AS				
		10^6 CFU/g of dry soil						
Namysto	6.9	11	6.0	136	169	3.2	75.0	28.6
Harantiya Odeska	7.7	27	8.1	179	192	2.9	89.3	26.1
Lisova pisnya	8.4	31	9.2	199	223	2.8	92.1	36.5
Trudovnitsya Myronovska	8.8	36	9.4	217	298	2.9	111.0	33.7
MIP Dnipryanka	6.9	21	7.3	154	1,871	3.6	98.0	22.7
MIP Valenciya	8.5	32	8.8	200	265	2.6	132.0	35.5
Poliska 90	5.7	14	5.8	127	176	3.4	87.0	26.4

Table 2, Continued

Variant	Biomass of bacteria, t/ha	Bacteria, on media			Oligonitrophilic bacteria	Micromycetes	Streptomycetes	cellulolytic thous./g of dry soil
		SAA	SAA+WA	AS				
		10^6 CFU/g of dry soil						
Shchedrivka Kyivska	6.6	19	6.4	135	183	3.0	79.2	27.5
Tradytsiya Odeska	7.1	24	7.4	165	193	2.7	90.4	30.2
Manera Odeska	9.1	39	9.1	231	302	2.5	101.2	34.6
Lainer	8.4	33	8.7	202	244	2.8	112.3	31.2
Valenciya	8.5	35	8.6	210	276	2.8	130.0	33.0
$LSD_{0.5}$	1.0	2.4	1.2	23.0	20.1	0.4	17.0	2.7

The number of bacteria on different nutrient media (SAA, AS, SAA +WA) was not stable and varied in the range from 5.8 to 231 x 10^6 CFU/g of dry soil.

The results of the research revealed that the cultivation of different varieties of winter wheat demonstrates stable indicators of CO_2 emission intensity – from 5.2 to 7.0. Similarly, the dynamics of O_2 absorption did not exceed 5.3-6.8 (Table 3). This proves that the experiment soil creates optimal conditions for the life of microorganisms, thereby increasing its biological activity.

Table 3. The intensity of CO_2 emission and O_2 absorption in the soil during wheat cultivation using various agrotechnologies

Variant	The intensity of CO_2 emission and O_2 absorption, µg/h	
	CO_2	O_2
Namysto	5.7	5.5
Harantiya Odeska	6.4	6.4
Lisova pisnya	5.9	5.7
Trudovnitsya Myronovska	6.0	5.9
MIP Dnipryanka	5.9	5.9
MIP Valenciya	6.1	6.0
Poliska 90	5.2	5.3
Shchedrivka Kyivska	5.6	5.5
Tradytsiya Odeska	6.0	5.9
Manera Odeska	7.0	6.8
Lainer	6.7	6.6
Valenciya	6.7	6.5

Note: x/P = 0.05; t_{st} = 3.11

Thus, by analysing the number of microorganisms of the rhizosphere of winter wheat, it was determined that varietal specificity had a significant impact on the formation of the microbiome in different phases of plant growth and development, which is obviously an integral indicator of the functional and metabolic activity of soil microorganisms.

It was established that the number and composition of the microbial complex of the

winter wheat rhizosphere in the process of ontogeny significantly changes, especially in the ratio of the number of spore-forming and non-spore forms of microorganisms under the same conditions of agricultural technology of crop cultivation. The general pool of saprotrophic microorganisms of the rhizosphere is changing in favour of eco-plastic bacilli, therefore, the exploratory research of bioagents of the genus *Bacillus* is relevant for agricultural science and practices. Further comprehensive examinations will be carried out through the prism of assessing the diversity of isolates based on the results of microbiological, physiological, biochemical, molecular biological research methods.

CONCLUSIONS

The results of microbiological studies to determine the number and composition of the microbiome of winter wheat revealed the variability of microbial biomass by varietal variants. The activation of bacillary forms of microorganisms during plant ontogeny was established (increase in the number of spore-forming bacteria to 4.2×10^7 CFU/g in the variants of cultivation of individual varieties). Significant differentiation is observed in the analysis of the number of microorganisms of the main physiological groups depending on the variety of plants. Thus, the development of freely existing forms of microorganisms of the genus *Azotobacter* was detected. The number of micromycetes by varietal variants ranged from 38,270 to 53,450. CFU/g of soil. And the number of oligonitrophilic bacteria in the tilth layer of the soil in winter wheat crops during the growing season increased to 169-302 million CFU / g of soil, evidencing the ongoing nitrogen-fixation processes. The index of bacterial biomass under different varieties of winter wheat demonstrated a stable growth from 6 to 9 t/ha. At the same time, the number of bacteria on different nutrient media (SAA, AS, SAA +WA) was not stable and varied in the range from 5.8 to 231×10^6 CFU/g of dry soil. It was found that the cultivation of different varieties of winter wheat demonstrates stable indicators of CO_2 emission intensity – from 5.2 to 7.0. Similar results were observed for the process of O_2 absorption (less than 5.3-6.8).

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Особливості змін чисельності та складу мікробіому ризосфери озимої пшениці в процесі онтогенезу

Анотація. В агроекосистемах мікроорганізми є основним чинником ґрунтоутворення, живлення рослин та фітосанітарного стану ґрунту. Усі заходи, спрямовані на відновлення родючості ґрунту та підвищення продуктивності, екологічної безпеки сільськогосподарського виробництва, тісно пов'язані з діяльністю мікроорганізмів. Підвищена локальна активність, біомаса та різноманітність мікробіоти є одними з найважливіших характеристик, які відрізняють ризосферу від загального об'єму ґрунту. Метою досліджень було вивчення чисельності та складу мікробного комплексу ризосфери зернових культур (озимої пшениці різних сортів вітчизняної селекції) в процесі онтогенезу. Для проведення комплексу мікробіологічних досліджень були відібрані зразки ґрунту (чорнозем типовий), які були підготовлені з дотриманням стандартних вимог до пробопідготовки та зберігання зразків у лабораторних умовах. Аналіз ризосферних зразків ґрунту проводили на варіантах різних сортів озимої пшениці вітчизняної селекції. Чисельність ґрунтових мікроорганізмів визначали методом висіву суспензій на поживні середовища за загальноприйнятими в мікробіології методиками. Визначення загальної мікробної біомаси в ґрунті проводили регідратаційним методом, а інтенсивність "дихання" ґрунту за виділенням CO_2 та поглинанням O_2 визначали манометричним методом (апарат Варбурга). Встановлено, що сорти озимої пшениці впливали на формування мікробіому чорнозему типового. Чисельність і склад мікробного комплексу ризосфери пшениці озимої в процесі онтогенезу суттєво змінюється, особливо за співвідношенням кількості спороутворюючих і неспорових форм мікроорганізмів за однакових умов агротехніки вирощування культури. Загальний пул сапротрофних мікроорганізмів ризосфери демонструє варіабельність біомаси та зміни на користь екопластичних бацил. Виявлено збільшення кількості спороутворюючих бактерій до 4,2 х 107 КУО/г у варіантах вирощування окремих сортів. Вирощування різних сортів пшениці озимої демонструє стабільні показники інтенсивності емісії CO_2 - від 5,2 до 7,0. Аналогічна тенденція простежується і за коефіцієнтом поглинання O_2 (не більше 5,3-6,8)

Ключові слова: ґрунтові мікроорганізми, мікробна біомаса, сортова специфічність, інтенсивність емісії CO_2, динаміка поглинання O_2, спороутворюючі бактерії

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Changes in the Key Agrochemical Properties of Soddy-Podzolic Soil After Fertilisation of Jerusalem Artichoke with Sewage Sludge

Abstract. Studies have shown that the introduction of sewage sludge and composts based on it under Jerusalem artichoke significantly affects the change in agrochemical parameters of soddy-medium-podzolic soil, contributing to an increase in the content of alkaline-hydrolysed nitrogen compounds by 2.2-13.4 mg/kg of soil compared to the control and determining the content at the level of 51.2-56.5 mg/kg of soil in the upper (0-20 cm) and 27.9-31.6 mg/kg of soil – in the lower (20-40 cm) soil layer. The content of ammonium nitrogen compounds in the variants with fertiliser application fluctuated in a small range of values (16-21 mg/kg of soil) and increased under the influence of increasing fertilizer doses. Along with the change in the content of nitrate nitrogen, this contributed to an increase in the content of mineral nitrogen compounds in the soil in the range of 18.5-23.4 mg/kg of soil in the arable (0-20 cm) and 19.8-21.9 mg/kg of soil – in the subsoil (20-40 cm) layers, which is 1.7-2.2 mg/kg of soil higher than the control variant. The highest values of mineral nitrogen compounds were recorded in the variant where the highest dose of sewage sludge – 40 t/ha and mineral fertilisers were applied (N10P14K58). Despite a wide range of nitrogen content values for alkaline hydrolysed compounds and mineral nitrogenous compounds, their ratio remained stable and amounted to 2.3-2.6 in the upper and 1.3-1.5 in the lower (20-40 cm) soil layer, and also decreased with increasing fertiliser application dose. That is, this parameter varied insignificantly depending on the dose of fertiliser application. The content of mobile phosphorus compounds in the variants with the use of fertilisers fluctuated in the range of values (77.5-98.5 mg/kg of soil) and increased under the influence of sewage

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sludge and composts based on it, which exceeded the control values by 14.6-35.6 mg/kg of soil. The highest rates of mobile phosphorus compounds were recorded in the variant where sewage sludge was applied – 40 t/ha and N10P14K58.10P14K58. The introduction of sewage sludge at a dose of 20-40 t/ha contributed to an increase in the content of exchangeable potassium compounds at the level of 89.3-97.2 mg/kg of soil in the upper (0-20 cm) and 83.1-93.4 mg/kg of soil – in the lower (20-40 cm) layer, which is more than 42.1 mg/kg of soil exceeded the control variant. To a lesser extent, the content of exchangeable potassium compounds increased with the introduction of composts based on sewage sludge and straw. The correlation and regression analysis indicates that the coefficient of phosphorus concentration in the soil depends to the greatest extent on the content of its mobile compounds with the coefficient of determination R2 = 0.70. The potassium concentration coefficient closely (R2 = 0.91) correlates with the content of its metabolic compounds in the soil

Keywords: soil, fraction, nitrogen, phosphorus, potassium, concentration coefficient, correlation and regression analysis

RELEVANCE

Ukraine is demonstrating growing interest in growing crops for energy purposes, for which areas of mainly low-productive degraded soils are allocated outside crop rotations. Being characterised by high biological productivity, such crops respond well to the application of fertilisers, in particular organic fertilisers, which not only improve the nutrient regime of the soil but also contribute to the realisation of its bioproductive and ecological functions. Due to the acute shortage of conventional types of organic fertilisers in agriculture in Ukraine, there is a need to find alternative sources of organic raw materials for application as fertilisers for bioenergy crops.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Sewage sludge (SS), which accumulates in excess volumes in Ukraine, can be used as fertiliser, provided that the requirements of environmental safety of such use are met and the content of heavy metals and other pollutants in it is acceptable (Hrytsuliak & Lopushniak, 2017, Hetmanenko, 2016, Kholodna, 2016, Berdnikov *et al.*, 2019, Yang *et al*, 2015, Rossini *et al*, 2019). The use of SS for bioenergy crops has significant prospects and partially solves the problem of utilisation of its large accumulated reserves in the municipal sector, and also provides plants with the necessary macro- and microelements. Sewage sludge contains a significant amount of essential nutrients for the proper growth and development of plants (Onyshchuk *et al.*, 2004, Chebotko, 2000, Hetmanenko & Skrylnyk, 2017, Lamastra, 2018). Therefore, this raw material resource should be considered an important element of energy- and resource-saving environmentally friendly biological crop cultivation technologies, in particular, energy technologies. Another promising area is the preparation of composts based on SS and other organic materials, in particular, cereal straw, etc. Application of such composts enhances the humus-forming capacity of the soil due to the supply of additional organic substances and intensification of the development of beneficial microflora, which contributes to the improvement of the mineral nutrition regime of plants, which provides increased bioproductivity of agro phytocoenoses (Hospodarenko, 2015, Dubovyi *et al.*, 2018, Onyshchuk, 2004, Ruf, 2019).

A promising method of SS utilisation is using them as fertilisers, provided that they meet the regulatory requirements for the content of pollutants, which contributes to solving several problems at once: ensuring the supply of organic matter and nutrients to the soil and reducing the intensity of its accumulation in sludge maps of municipal enterprises (Madzhd *et al.*, 2017, Yakymenko, 2001, Krutyakova, 2020).

The purpose of this study is to determine the changes in agrochemical parameters of sod-podzolic soil with the application of different doses of fertilisers based on SS for Jerusalem artichoke.

MATERIALS AND METHODS

Studies on the efficiency of sewage sludge application into one of the most promising bioenergy crops – Jerusalem artichoke – were conducted in a field experiment on sod-podzolic soils of Ivano-Frankivsk oblast (Lopushniak & Hrytsuliak, 2017).

The soil of the experimental plot is soddy-medium podzolic. The redistribution of the colloidal fraction of the eluvial and illuvial horizons is distinctly pronounced. Humus-eluvial (NE) horizon up to 18-25 cm, darkish grey, lumpy-dusty, loose, with SiO_2 particles. Eluvial horizon (E) up to 45 cm yellowish-whitish. The illuvial (I) horizon is characterised by a pronounced alternation of whitish sand layers with dense red-brown loam layers up to 8 cm. The studied soil was characterised by the following agrochemical indicators: humus content in the arable (0-20 cm) layer – 2.0%, salt pH – 4.8, hydrolytic acidity – 3.1 mmol/100 g of soil. The content of alkaline hydrolysed nitrogen compounds was 47 mg/kg of soil, mobile phosphorus compounds – 64, and exchangeable potassium – 42 mg/kg of soil (Lopushniak & Hrytsuliak, 2017).

The scheme of the experiment consisted of the following options: 1 – control (without fertilisers); 2 – $N_{60}P_{60}K_{60}$; 3 – $N_{90}P_{90}K_{90}$; 4 – SS 20 t/ha + $N_{50}P_{52}K_{74}$; 5 – SS 30 t / ha + $N_{30}P_{33}K_{66}$; 6 – SS 40 t/ha + $N_{10}P_{14}K_{58}$ 7 – compost (SS + straw in the ratio (3:1) 20 t/ha + $N_{50}P_{16}K_{67}$; 8 – compost (SS + straw in the ratio (3: 1)) 30 t/ha + $N_{30}K_{55}$. In variants of experiments 3-8, SS and compost were applied with a compensatory dose of mineral fertilisers based on the total number of nutrients applied $N_{90}P_{90}K_{90}$.

The study was carried out using sludge with the following characteristics: humidity – 76%, pH – 8.1, the content of ash elements, nitrogen, phosphorus and potassium was 5.0%, 4.0%, 3.8% and 1.6% (in terms of absolutely dry matter), respectively. Composts with SS and straw of grain crops in the ratio of 3:1 had the following chemical composition: organic matter content – 78%, pH_{HCl} – 7.2, the nitrogen of alkaline-hydrolysed compounds – 200.3 mg/kg of compost, phosphorus of mobile compounds – 371.2, potassium of exchange compounds – 115.4 mg/kg of compost. The chemical composition of non-traditional types of organic fertilizers was determined in the laboratory of analytical support of agrochemical research of the Ivano-Frankivsk branch of the State Institution Institute of Soil Protection of Ukraine "Derzhgruntokhora" according to generally accepted methods (Yakist gruntu[1], 2008, Yakist gruntu[2], 2008, Yakist gruntu, 2006).

The total area of the experimental plot is 63 m^2, and the accounting area is 35.0 m^2.

To evaluate the nitrogen fund of the soil after the application of SS, the content of various nitrogen compounds in the soil was measured. To determine the characteristics of the transformation of phosphorus and potassium compounds in the soil, the concentration coefficients of their compounds were calculated by the ratio of the content of each element in the experimental variants to its content in the background area (variant 1). The value of the concentration coefficients indicates the intensity of leaching processes in the soil (Madzhd *et al.*, 2016).

During the period of experimental research between 2016-2020, the content of total nitrogen in the studied soil was determined in the modification of the National Scientific Centre A. N. Sokolovsky Institute of Soil Science and Agrochemistry; DSTU 4729: 2007. Determination of nitrate and ammonium nitrogen in the modification of the NSC A. N. Sokolovsky Institute of Soil Science and Agrochemistry (Yakist gruntu[1], 2008, Yakist gruntu[2], 2008, Kholodna, 2016). Determination of mobile compounds of phosphorus and potassium by the Kirsanov method in the modification of the NSC A. N. Sokolovsky Institute of Soil Science and Agrochemistry; DSTU 4405:2005 (Yakist gruntu, 2006).

RESULTS

Studies have shown that the use of fertilisers significantly influenced the formation of the nitrogen fund of soddy-medium-podzolic soil (Table 1).

Table 1. The content of nitrogen compounds of different fractions in the layer of 0-40 cm of sod-podzolic soil for the application of sewage sludge and compost under Jerusalem artichoke, the average for 2016-2019

Variant	Soil layer, cm	Content of various nitrogen fractions in the soil			
		Ammonium	Nitrate	Alkaline hydrolysed	
		N_{NH4}^+	N_{NO3}^-	$N_{NH4}^+ + N_{NO3}^-$	
		mg/kg of soil			
1. Without fertilisers (control)	0 - 20	15	1.68	16.78	43.12
	20 - 40	16	1.60	17.60	25.78
2. $N_{60}P_{60}K_{60}$	0 - 20	16	2.51	18.51	48.18
	20 - 40	18	1.84	19.84	27.83
3. $N_{90}P_{90}K_{90}$	0 - 20	18	2.75	20.75	49.34
	20 - 40	18	2.31	20.31	28.41
4. SS - 20 t/ha + $N_{50}P_{52}K_{74}$	0 - 20	19	2.54	21.54	51.20
	20 - 40	19	2.12	20.12	27.91
5. SS - 30 t/ha + $N_{30}P_{33}K_{66}$	0 - 20	20	2.29	22.29	52.41
	20 - 40	19	2.72	21.72	29.04
6. SS - 40 t/ha + $N_{10}P_{14}K_{58}$	0 - 20	21	2.41	23.41	56.49
	20 - 40	19	2.96	21.96	31.62
7. compost (SS + straw (3:1)) - 20 t/ha + $N_{50}P_{16}K_{67}$	0 - 20	19	1.94	20.94	52.04
	20 - 40	19	1.62	20.62	28.56
7. compost (SS + straw (3:1)) - 20 t/ha + $N_{30}K_{55}$	0 - 20	19	2.03	22.07	52.91
	20 - 40	19	2.56	21.56	30.12
LSD 0.5, mg/kg of soil	0 - 20	1.02	0.1	1.3	4.6
	20 - 40	1.01	0.1	1.1	2.2

In particular, the use of mineral fertilisers at a dose of $N_{60}R_{60}K_{60}$ contributed to an increase in the nitrogen content of alkaline hydrolysed compounds by 5 mg/kg of soil in the upper (0-20 cm) and 2 mg/kg in the lower (20-40 cm) layer, which amounted to 48.2 and 27.8 mg/kg of soil, respectively (Lopushniak & Hrytsuliak, 2017, Hrytsuliak & Lopushniak, 2017). An increase in the dose of nitrogen application with mineral fertilisers contributed to an increase in the nitrogen

content of alkaline hydrolysed compounds in the soil. The application of OSV at a dose of 20-40 t/ha with the corresponding balance dose of mineral fertilisers caused an increase in alkaline hydrolysed nitrogen compounds by 8.1-13.3 mg/kg in the upper (0-20 cm) soil layer and by 28-31 mg/kg in the lower (20-40 cm). Slightly lower rates of growth of alkaline hydrolysed nitrogen compounds were achieved by the introduction of composts based on sewage sludge and straw, the content of alkaline-hydrolyzed nitrogen compounds was 52.0-52.9 in the upper layer of soil and 28.6-30.1 mg/kg of soil in the lower layer, which significantly exceeded the control variant.

The content of ammonium nitrogen compounds in the variants with fertiliser application fluctuated in a small range of values (16-21 mg/kg of soil) and increased under the influence of increasing fertilizer doses. Along with the change in the nitrogen content of nitrate compounds, this contributed to the formation of mineral nitrogen compounds in the soil in the range of 18.5-23.4 mg/kg of soil in the arable (0-20 cm) layer and 19.8-21.9 mg/kg of soil – in the subsoil (20-40 cm) layer. The highest rates of mineral nitrogen compound content were recorded in variant 6, where the highest dose of sewage sludge – 40 t/ha and the corresponding amount of mineral fertilisers were applied ($N_{10}P_{14}K_{58}$). The introduction of SS-based compost (variants 7 and 8) provided the content of mineral nitrogen compounds in the range of 21.5-22.1 mg/kg of soil.

Despite the wide range of values of the nitrogen content of alkaline hydrolysed compounds and mineral compounds, their ratio was 2.3-2.6 in the upper layer and 1.3-1.5 in the lower layer (20-40 cm) and reduced with increasing doses of fertilisers. Thus, the ratio of the content of alkaline hydrolysed nitrogen compounds to the nitrogen content of mineral compounds can be considered a relatively stable indicator of soil characteristics, which does not change significantly depending on the use of fertilisers.

The use of SS and composts based on it led to a significant increase in the content of mobile phosphorus compounds and exchangeable potassium compounds in sod-podzolic soil. This increase was observed in all variants of the experiment on the soil profile to a depth of 60 cm. Deeper than 60 cm, the difference in the experimental variants was less pronounced, and in relation to phosphorus – almost imperceptible (within the error).

The highest values of phosphorus q potassium content were recorded in the variants with the application of fresh sewage sludge and amounted to 98.5 and 97.2 mg/kg of soil, respectively, mobile phosphorus compounds and exchangeable potassium in the upper (0-20 cm) layer of soil (variant with the highest dose of sewage sludge application – variant 6). In the subsoil (20-40 cm) layer, the difference was also significant in the experimental variants compared to the control, but the content of mobile phosphorus compounds changed to a lesser extent than the content of exchangeable potassium compounds. For applying fertilisers in a dose of $N_{60-90}P_{60-90}K_{60-90}$, the concentration coefficient of phosphorus compounds was 1.01–1.17 in the arable soil layer (0-20 cm), and along the soil profile to a depth of 60 cm increased and varied within 1.17-1.30 (20-40 cm) (see Table 2). The highest values of the concentration coefficients of phosphorus and potassium compounds were recorded in the variants with the introduction of fresh SPS, namely variant 6 (SS - 40 t/ha + $N_{10}P_{14}K_{58}$) and amounted to 1.28 and 2.36 mg/kg of soil, respectively, in the upper (0-20 cm) soil layer. In the subsoil layer (20-40 cm), the concentration of phosphorus and potassium compounds was 1.33 and 2.28, respectively.

Table 2. The impact of sewage sludge and composts based on it on the content of mobile phosphorus compounds and exchangeable potassium compounds in soddy-medium-podzolic soil, the average for 2016-2019

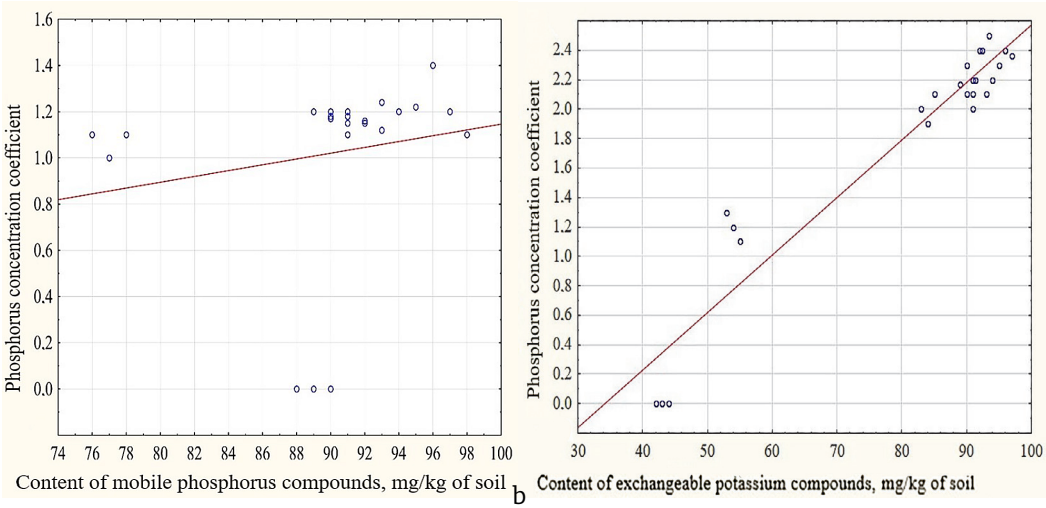
Variant	Soil layer, cm	Content of		Compound concentration coefficient	
		mobile phosphorus compounds	exchangeable potassium compounds	P	K
		mg/kg of soil			
1. Without fertilisers (control)	0 - 20	62.9	41.2	-	-
	20 - 40	70.3	40.9	-	-
	40 - 60	49.7	37.5	-	-
	60 - 80	30.6	32.2	-	-
2. $N_{60}P_{60}K_{60}$	0 - 20	77.5	53.9	1.01	1.30
	20 - 40	82.2	50.9	1.17	1.24
	40 - 60	53.8	43.6	1.08	1.16
	60 - 80	30.7	36.7	1.00	1.14
3. $N_{90}P_{90}K_{90}$	0 - 20	90.4	83.4	1.17	2.02
	20 - 40	91.7	75.3	1.30	1.84
	40 - 60	60.3	53.8	1.21	1.43
	60 - 80	32.7	35.9	1.07	1.11
4. SS - 20 t/ha + $N_{50}P_{52}K_{74}$	0 - 20	91.2	89.3	1.18	2.17
	20 - 40	92.4	83.1	1.31	2.03
	40 - 60	70.2	56.9	1.41	1.52
	60 - 80	33.7	38.5	1.01	1.20
5. SS - 30 t/ha + $N_{30}P_{33}K_{66}$	0 - 20	93.5	91.8	1.21	2.23
	20 - 40	88.2	88.2	1.25	2.16
	40 - 60	78.5	55.2	1.58	1.47
	60 - 80	34.2	37.6	1.18	1.17
6. SS - 40 t/ha + $N_{10}P_{14}K_{58}$	0 - 20	98.5	97.2	1.28	2.36
	20 - 40	93.7	93.4	1.33	2.28
	40 - 60	82.5	60.3	1.66	1.61
	60 - 80	33.5	38.3	1.09	1.19
7. compost (SS + straw (3:1)) - 20 t/ha + $N_{50}P_{16}K_{67}$	0 - 20	91.2	87.5	1.18	2.12
	20 - 40	88.4	84.4	1.26	2.06
	40 - 60	79.2	57.8	1.59	1.54
	60 - 80	33.7	39.3	1.10	1.22
7. compost (SS + straw (3:1)) - 20 t/ha + $N_{30}K_{55}$	0 - 20	94.2	93.2	1.22	2.26
	20 - 40	90.5	88.9	1.29	2.17
	40 - 60	82.7	59.2	1.66	1.58
	60 - 80	34.6	39.1	1.13	1.21
LSD 0.5, mg/kg of soil	0 - 20	14.8	14.4	0.21	0.27
	20 - 40	10.1	12.1	0.03	0.05
	40 - 60	6.7	8.3	0.01	0.01
	60 - 80	3.5	4.6	0.01	0.01

The use of composts based on SS (variants 7 and 8) provided the concentration coefficients of phosphorus and potassium compounds in the range of 1.10-1.66 and 1.21-2.26, respectively. The lowest concentration coefficients of phosphorus and potassium compounds were observed in the soil profile at a depth of 60-80 cm, due to a decrease in the content of phosphorus and potassium compounds.

According to the correlation and regression analysis, the phosphorus concentration coefficient (Fig. 1) depends mainly on the content of mobile connections in soil with coefficients of determination $R^2 = 0.70$, and correlation $r = 0.73$. The multiple regression equation can be presented as follows:

$$y = -0.1107+0.0126*x,$$

where x – content of mobile phosphorus compounds in soil, mg/kg of soil; in – coefficient of phosphorus concentration.



a b

Figure 1. Correlation dependence of the concentration coefficient of phosphorus (a) and potassium (b) on the content of their compounds in sod-podzolic soil.

Based on the correlation and regression analysis, the coefficient of potassium concentration depends most of all on the content of its metabolic compounds in the soil with coefficients of determination and correlation $R^2 = 0.91$, $r = 0.95$. The multiple regression equation can be presented as follows:

$$y = -1.3341+0.0391*x,$$

where, x – content of exchangeable potassium compounds in soil, mg/kg of soil; y – potassium concentration coefficient.

CONCLUSIONS

Application of wastewater sludge in doses of 20-40 t/ha with the corresponding balance dose of mineral fertilisers at the rate of $N_{90}P_{90}K_{90}$ causes a significant increase in the content of the main elements of mineral nutrition in soddy-medium-podzolic soil, in particular, the nitrogen content of alkaline hydrolysed compounds at the level of 51.2-56.5 mg/kg of soil in the upper (0-20 cm) layer and 27.9-31.6 – in the lower (20-40 cm) layer, which, respectively, by 16-24% and 8-18% exceeded the control variant on average for three years of research.

The content of mobile phosphorus compounds and exchangeable potassium in the variants with the application of sewage sludge in the upper 0-20 soil layer ranges from 77.5-98.5 mg/kg of soil and 89.3-97.2 mg/kg of soil and increases under the influence of increasing doses of sewage sludge and composts based on it. Their highest values were recorded in the variant where SS was applied – 40 t/ha and $N_{10}P_{14}K_{58}$ (variant 6), which exceeded the control variant of phosphorus and potassium by 35.4 and 55.9 mg/kg of soil, respectively.

Such a dose of fertilizer application results in the highest concentration coefficient of phosphorus and potassium compounds at the level of 1.28 and 2.36 respectively in the layer of 0-20 cm of soddy-medium podzolic soil. The results of correlation and regression analysis indicate that the dependence of the coefficient of phosphorus concentration in the soil on the content of its mobile compounds is determined by the coefficients of determination $R^2 = 0.70$, and correlation $r = 0.73$, and the potassium concentration coefficient in the soil depends most of all on the content of exchangeable potassium compounds with determination and correlation coefficients $R^2 = 0.91$, $r = 0.95$, respectively.

Thus, in further studies, it is important to determine the trends in the stabilisation of agrochemical parameters of soddy-medium-podzolic soil under conditions of repeated fertilisation of Jerusalem artichoke in permanent culture, and the environmental impact of the use of such types of fertilisers on the soil environment and the conditions of growth and development of the crop.

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Зміни основних агрохімічних властивостей дерново-підзолистого ґрунту після удобрення топінамбура осадом стічних вод

Анотація. Дослідженнями встановлено, що внесення осаду стічних вод та компостів на його основі під топінамбур суттєво впливає на зміну агрохімічних показників дерново-середньопідзолистого ґрунту, сприяючи збільшенню вмісту лужногідролізованих сполук азоту на 2,2-13,4 мг/кг ґрунту порівняно з контролем і визначаючи їх вміст на рівні 51,2-56,5 мг/кг ґрунту у верхньому (0-20 см) та 27,9-31,6 мг/кг ґрунту — у нижньому (20-40 см) шарі. Вміст амонійних сполук азоту у варіантах із внесенням добрив коливався в невеликому діапазоні значень (16-21 мг/кг ґрунту) і зростав під впливом збільшення доз добрив. Поряд зі зміною вмісту нітратного азоту це сприяло збільшенню вмісту мінеральних сполук азоту в ґрунті в межах 18,5-23,4 мг/кг ґрунту в орному (0-20 см) та 19,8-21,9 мг/кг ґрунту - в підорному (20-40 см) шарах, що на 1,7-2,2 мг/кг ґрунту вище контрольного варіанту. Найвищі значення вмісту мінеральних сполук азоту зафіксовано у варіанті, де вносили найбільшу дозу осаду стічних вод — 40 т/га та мінеральні добрива (N10P14K58). Незважаючи на широкий діапазон значень вмісту азоту лужногідролізованих сполук та мінеральних азотовмісних сполук, їх співвідношення залишалося стабільним і становило 2,3-2,6 у верхньому та 1,3-1,5 у нижньому (20-40 см) шарі ґрунту, а також зменшувалося зі збільшенням дози внесення добрив. Тобто цей показник змінювався несуттєво залежно від дози внесення добрив. Вміст рухомих сполук фосфору у варіантах із застосуванням добрив коливався в межах значень (77,5-98,5 мг/кг ґрунту) і зростав під впливом осаду стічних вод та компостів на його основі, що перевищувало контрольні значення на 14,6-35,6 мг/кг ґрунту. Найвищі показники вмісту рухомих сполук фосфору зафіксовано у варіанті з внесенням осаду стічних вод — 40 т/га та N10P14K58,10P14K58. Внесення осаду стічних вод у дозі 20-40 т/га сприяло підвищенню вмісту обмінних сполук калію на рівні 89,3-97,2 мг/кг ґрунту у верхньому (0-20 см) та 83,1-93,4 мг/кг ґрунту — у нижньому (20-40 см) шарі, що на понад 42,1 мг/кг ґрунту перевищувало контрольний варіант. Меншою мірою вміст обмінних сполук калію збільшувався при внесенні компостів на основі осаду стічних вод та соломи. Кореляційно-регресійний аналіз свідчить, що коефіцієнт концентрації фосфору в ґрунті найбільшою мірою залежить від вмісту його рухомих сполук з коефіцієнтом детермінації R^2=0,70. Коефіцієнт концентрації калію тісно (R^2 = 0,91) корелює з вмістом його обмінних сполук у ґрунті

Ключові слова: ґрунт, фракція, азот, фосфор, калій, коефіцієнт концентрації, кореляційно-регресійний аналіз

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Effect of Systematic Fertilisation on Soil Fertility in the Cultivation of Corn for Grain

Abstract. The article presents the results of studies on the systematic application of organic and mineral fertilisers on the fertility of grey forest soil and the formation of corn yield. It was determined that in the five-field crop rotation during the cultivation of crops, the formation of soil backgrounds with different physicochemical properties took place. Application of litter manure (direct action) at a dose of 60 t/ha against the background of moderate fertiliser rates ($N_{40-80}R_{30-60}K_{40-80}$) contributed to the neutralisation of the soil solution to the values of a slightly acidic reaction (pHsal -5.2-5.3 units), while in the absence of manure (mineral fertiliser system), the pHsal remained within the range of medium acidic reaction. The most effective in terms of humus soil condition was the organic-mineral fertiliser system (12 t/ha of manure + $N_{80}P_{60}K_{80}$) and organic (12 t/ha of manure per 1 ha of crop rotation area), respectively, the total humus content was 1.35 and 1.37% or in percentage terms 25-27% higher compared to the control (without fertilisers) – 1.08 t/ha. Optimisation of nutrient regime indicators (hydrolysed nitrogen, mobile forms of phosphorus and potassium) of the soil at the end of the rotation was provided by the organo-mineral fertiliser system ($N_{100}P_{60}K_{100}$ against 60 t/ha of manure). The highest productivity of corn per grain (9.49 t/ha) was provided by the organic-mineral fertiliser system (60 t/ha of manure + $N_{100}P_{60}K_{100}$), which is 86% higher than the control variant (without fertilisers), under such conditions the highest yield of crude protein was obtained – 0.98 t/ha

Keywords: content, nitrogen, phosphorus, potassium, soil fertility, fertiliser system, yield, protein collection

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RELEVANCE

Corn is one of the most strategic agricultural crops, which by its economic and biological properties is used in various industries, including livestock, food and processing industries. Corn grain production is a complex and costly process with strict adherence to technological discipline, and timely and high-quality performance of all technological operations (Tsikov, 2003; Zubets, 2004).

High productivity of any crop, including corn, mainly depends on the technology of its cultivation, the main component of which is a properly selected fertiliser system. This contributes to the cultivation of the arable layer and improves its water-air, thermal and nutrient regimes for growing crops. Fertilisers regulate biological and agrochemical processes occurring in the soil, the intensity of decomposition and accumulation of organic matter, accumulation of nutrients in the soil (Volodin V.M., 2000; Degodyuk E.G., Degodyuk S.E., 2006). Today, there is still no precise stance on the rational use of fertilisers for agricultural crops, including corn. Therefore, to increase the level of realisation of the biological potential of the crop in grey forest soil, it is important to introduce effective cultivation technologies into production, which should be based on the widespread use of evidence-based fertiliser systems. Answers to these questions can be obtained in stationary experiments, which help to identify and study the most effective components of fertiliser systems. Therefore, research in this area is relevant. An in-depth study of the effect of agrochemicals on potential soil fertility, crop yield and quality remain important.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The realisation of the available agricultural resource potential is achieved through the use of significant resource sources of anthropogenic origin, in particular: mineral fertilisers, ameliorants, and plant protection products. At the present stage of agricultural production, the issue of developing new technologies for growing crops, as well as studying their impact on changes in soil properties with their long-term use, is acute. This necessitates constant monitoring of changes in soil properties, in particular, nutrient regime, nutrient cycle, and humus content, as the most important indicator of fertility and agroecological status (Mukha *et al.*, 2001; Litvinova *et al.*, 2019). The humus content ensures the resistance of soils to external influences and thus supports one of the main functions – their biogenicity (Boyko *et al.*, 2019; Litvinov *et al.*, 2019). The humus content contributes to the resistance of soils to external influences and thus supports one of the main functions – their biogenicity (Boyko *et al.*, 2019; Litvinov *et al.*, 2019). The importance of determining optimal doses of mineral fertilisers in crop cultivation technologies is well known (Pellerin Sylvain, 2000; Likhochvor, 2002; Shevchenko, 2018). Therefore, in the new economic conditions, there is a need to improve traditional fertiliser systems and develop new types of fertilisers that can quickly respond to changes in the market (Mazur G.A., 2008; Moskalenko A.M., 2013; Polupan M.I. *et al.*, 2009). According to many authors, corn is a very nutrient-demanding plant. To produce one ton of grain yield together with the total mass of the vegetative part, 25 kg of N, 13 kg of P2O5 and 22 kg of K2O per active substance are required. That is, corn is a nitrogenophile and potassiumophile, as it requires a large amount of nitrogen and potassium, and the requirement for phosphorus in corn is average. Therefore, its cultivation in the conditions of grey forest soil requires optimal ways of fertilisation with the inclusion of organic components in the fertiliser system.

The lack of even one of the elements in the nutrient balance slows down the growth and development of plants – the formation of leaves, flowering panicles, fertilisation and the formation of corn grain. It is established that nitrogen deficiency delays development and reduces the productivity of plants. Lack of phosphorus nutrition negatively affects the conditions for the formation of the root system, affects the development of reproductive organs, plants ripen much later, etc. (Movsesyan, 2009; Vlashchuk, 2016).

It is important to note that increasing crop productivity remains the main issue of agricultural production. And improving quality contributes towards providing the market with products of greater value. Moreover, it is important that improving the quality of agricultural products is the most effective factor in raising the economic efficiency of its production (Mazur, 2017; Shevchenko, 2018;). Therefore, it is particularly relevant to address the whole range of issues related to ensuring a sustainable increase in the production of high-quality corn grain in Ukraine, including the optimisation of the nutrition system.

The purpose of the study is to establish the indicators of grey forest soil fertility and corn productivity depending on the agrochemical load in field crop rotation.

MATERIALS AND METHODS

The research was conducted during 2017-2019 in a stationary experiment of the Department of Agrochemistry of the National Research Center "Institute of Agriculture of NAS" on grey forest coarse-dusty light loamy soil in a five-field crop rotation: corn for grain, spring barley, buckwheat, peas, winter wheat. The following physical, chemical and agrochemical parameters were determined in the initial soil samples. The average soil sample of arable layer 0-20 cm was characterised by the following agrochemical parameters: ph $_{KCl}$ – 4,8 potentiometrically; hydrolytic acidity – 1.61 mg-eq. per 100 g by Kappen, the content of hydrolysed nitrogen – 50.8 mg/kg of soil according to Kornfield; mobile phosphorus – 188 mg/kg of soil, mobile potassium – 100 mg/kg of soil according to Chirikov, total humus content – 1.20% (by Tyurin). The study of the agronomic value of organic fertilisers – bedding-free cattle manure was conducted. It was found that the content of basic nutrients in 1 ton of manure is: N – 4.0 kg, P_2O_5 – 2.0 kg, K_2O – 4.0 kg.

The experiment was established in 2011 and conducted in three fields, includes 11 variants, and was replicated four times. The sown area of the plot is 52 m^2, and the accounting area is 22 m^2. Cattle bedding manure was applied under corn for grain with a single dose of manure – 60 t/ha, mineral fertilisers – $N_{40}P_{30}K_{40}$. The experiment scheme includes the following fertiliser options: 1 – no fertilisers (control variant); 2 – 60 t/ha of manure; 3 – 60 t/ha f manure+ $N_{40}P_{30}K_{40}$; 4 – 60 t/ha of manure+ $N_{80}P_{60}K_{80}$; 5 – $N_{40}P_{30}K_{40}$; 6 – $N_{80}P_{60}K_{80.}$ Corn hybrid – Trubizh, listed in the State Register of Plant Varieties of Ukraine.

Soil samples were taken during the cultivation of corn for grain. The samples were analysed for: total humus content – by Tyurin; ph$_{K\text{-}Cl}$ – potentiometrically (DSTU ISO 10390:2001); hydrolytic acidity – by Kappen (GOST 26212-91); content of hydrolysed nitrogen – by Cornfield; content of mobile phosphorus and potassium – in grey forest soil – by Chirikov (DSTU 4115: 2002). The qualitative composition of corn grain was determined by infrared spectroscopy on an Infratek 1241 infrared analyser (DSTU 4117: 2007). The yield of corn grain was determined by the weight method, separately, including moisture content.

RESULTS AND DISCUSSION

The application of fertilisers in a stationary experiment on grey forest soil using the traditional system of their direct application created a tendency to differentiation in terms of potential soil

fertility. However, the application of litter manure both under direct action at a dose of 60 t/ha and against the background of moderate fertiliser rates ($N_{40-80}R_{30-60}K_{40-80}$) contributed to the neutralisation of the soil solution to the values of a slightly acidic reaction (pHsal – 5.2-5.5), while in the absence of manure (mineral fertiliser system), the pHsal remained within the range of medium acidic reaction. This indicates that the process of systematic fertilisation affects changes in the physical and chemical parameters of the arable layer of grey forest soil.

The results of the research showed that with a mineral fertilisation system, hydrolytic acidity in the arable (0-20 cm) layer was close to 1.77 mg-eq. per 100 g of soil, which indicates the need for liming, except for fertilisation systems with the use of organic fertilisers both separately (60 t/ha) and against the background of mineral fertilisers applied in moderate rates ($N_{40}R_{30}K_{40}$) (Table 1).

Table 1. The effect of fertilisers on the fertility of arable (0-20 cm) layer of grey forest soil in the field experiment, 2017-2019

Fertilisers per 1 ha of arable land		pHsal	Hydrol. qty, mg-eq per 100 g of soil	Humus content, %	Hydrolysed nitrogen	Mobile	
manure, t	NPK, kg					phosphorus P2O5	potassium K2O
					mg/kg		
No fertilisers (control)		5.4	1.36	1.08	50.8	160.0	85.8
Organic fertiliser system							
60	–	5.5	1.40	1.37	80.0	255.5	137.2
Organic-mineral fertiliser system							
60	$N_{40}P_{30}K_{40}$	5.3	1.45	1.30	75.0	243.0	132.5
60	$N_{80}P_{60}K_{80}$	5.2	1.47	1.35	78.0	265.5	147.5
Mineral fertiliser system							
-	$N_{40}P_{30}K_{40}$	4.9	1.74	1.28	71.0	257.0	120.5
-	$N_{80}P_{60}K_{80}$	4.6	1.77	1.24	74.0	260.0	128.5
LSD_{05}		0.1	0.08	0.02	0.7	4.0	3.0

Note: direct effect of litter manure

During the years of research, the tendency is observed to reproduce the content of total humus in the arable layer (0-20 cm) of the soil, so in the organic fertiliser system, the content of this indicator exceeded the initial level in percentage terms by 13%, at the initial values it was in absolute units – 1.14%. The most effective were both the organic-mineral fertiliser system (60 t/ha of manure + $N_{100}P_{60}K_{100}$) and organic (60 t/ha of manure), respectively, the content of total humus was 1.35 and 1.37% or 25-27% higher in percentage terms compared to the control (no fertilisers) – 1.08 t/ha. When using purely mineral fertilisers, the humus content in the arable layer was 1.24-1.28% or 14-18% higher than the control variant.

In all variants with fertilisation, there was an increase in the content of hydrolysed nitrogen from 71.0 to 80.0 mg/kg of soil with a content of 50.8 mg/kg in the control without fertilisers. The most active processes of accumulation of hy-

drolysed nitrogen up to 80.0 mg/kg in the layer 0-20 cm were observed with the application of organic fertilisers of 60 t/ha and ($N_{80}P_{60}K_{80}$) against the background of the aftereffect of 60 t/ha of manure. In terms of mineral content, its content was only 71.0-74.0 mg/kg, which is on average 45% higher than the control variant with a gradation of very low soil supply of this form of nitrogen.

It was established that given the increased level of supply of mobile phosphorus in the soil before the experiment, during its systematic conduct, there was an accumulation of this element corresponding to the amount of phosphorus applied as part of organic and mineral fertilisers. With the content of mobile phosphorus in the arable (0-20 cm) layer of soil in the control variant in the amount of 160.0 mg/kg of soil, its greatest increase occurred in the organic-mineral fertiliser system (60 t/ha of manure + $N_{100}P_{60}K_{100}$) – 265.5 mg/kg of soil, and purely mineral fertiliser system with the same rate of fertiliser.

Thus, the content of mobile phosphorus was within the limits that correspond to the gradation of a very high level of provision with this element. The findings suggest that with the systematic application of fertilisers, the content of mobile phosphorus in the root layer of the soil will gradually increase.

The use of organic and mineral fertilisers for crops contributed to an increase in the content of mobile potassium in the soil on average from 120 to 147 mg K_2O per 1 kg of soil while maintaining its content within the high supply in the soil. When the K_2O content in the control group without fertilisers was 85.8 mg/kg of soil, its increase (by 51.4 and 61.7 mg/kg of soil) was observed, respectively, with the application of increased NPK, both separately and against the background of 60 t/ha of manure.

The analysis of the research results showed that the accumulation of mobile potassium in the soil is slower, which can be explained by its transition to non-exchangeable forms and removal by crops.

It should be noted, that the content of hydrolysed nitrogen in both control and fertilised variants at the end of the rotation corresponded to a gradation of very low supply, and the content of mobile phosphorus – high supply, with an increase compared to the control variant (no fertilisers) by 62% for the organic-mineral fertiliser system $N_{80}P_{60}K_{80}$ on the background of 60 t/ha of manure. With the systematic application of organic and mineral fertilisers for corn for grain, there was a clear upward trend (by 61.7 mg/kg of soil) – organic-mineral fertiliser system, the content of mobile potassium, which compensates for its constant deficit in the soil, on average, its content ranged from 120-147 mg/kg of soil.

Creating necessary fertility levels of grey forest soil creates conditions for obtaining sustainable corn yields with a consistent quality of the main product. The highest grain yield in the control variant (no fertilisers) of 5.1 t/ha was 4.39 t/ha, which was obtained at the aftereffect of 60 t/ha of manure and direct action of double rate of mineral fertilisers ($N_{80}P_{60}K_{80}$), which is 86% higher than the yield in the control variant without fertilisers and 1.39 t/ha more effective than the single rate of NPK against the background of manure aftereffect (Fig. 1, 2).

It was determined that under the organic fertiliser system, the increase in corn yield (60 t/ha of crop rotation area) was 2.9 t/ha or higher by 56% compared to the control without fertilisers. The use of mineral fertilisers (mineral fertiliser system), in its pure form, resulted in increased yields of corn grain – at a single rate of 1.89 t/ha, at double rates – 3.01 t/ha, or respectively by 37 and 59% compared to the control (without fertilisers). Such a trend of producing the main crop at a sufficient level is consistent with the indicators of soil fertility and the intensity of biological processes in it.

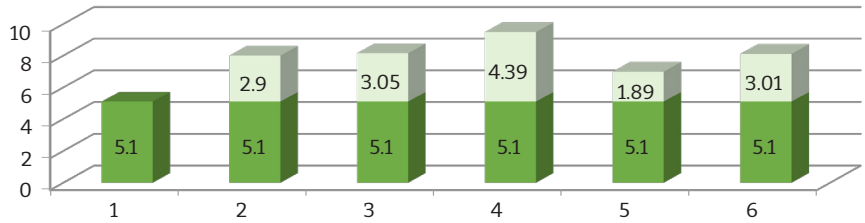

Figure 1. Effect of different fertiliser systems on corn grain yield, t/ha, the average for 2017-2019
Note: Variant 1 – no fertilisers (control); 2 – 60 t/ha of manure; 3 – 60 t/ha of manure+ $N_{40}P_{30}K_{40}$; 4 – 60 t/ha of manure+ $N_{80}P_{60}K_{80}$; 5 – $N_{40}P_{30}K_{40}$; 6 – $N_{80}P_{60}K_{80}$

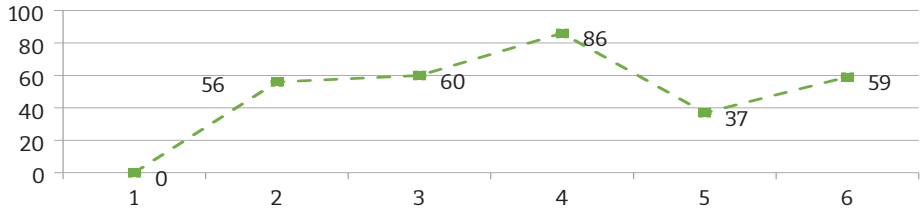

Figure 2. Effect of different fertilisation systems on corn grain growth, %, the average for 2017-2019
Note: Variant 1 – no fertilisers (control); 2 – 60 t/ha of manure; 3 – 60 t/ha of manure+ $N_{40}P_{30}K_{40}$; 4 – 60 t/ha of manure+ $N_{80}P_{60}K_{80}$; 5 – $N_{40}P_{30}K_{40}$; 6 – $N_{80}P_{60}K_{80}$

One of the main indicators of corn grain quality is the crude protein content. The quality of corn grain tends to raise this index in the case of the application of organic and mineral fertilisers. At the same time, the main role in the accumulation of protein belongs to nitrogen. The highest content of crude protein was obtained by applying the organic-mineral fertiliser system at a rate of 60 t/ha of manure + $N_{40}P_{30}K_{40}$ and amounted to 10.64, as compared to the control variant – 9.36%. The variant with organic fertilisers was at the level of 10.08%, under a purely mineral system at a single rate – 10.29 (Fig. 3).

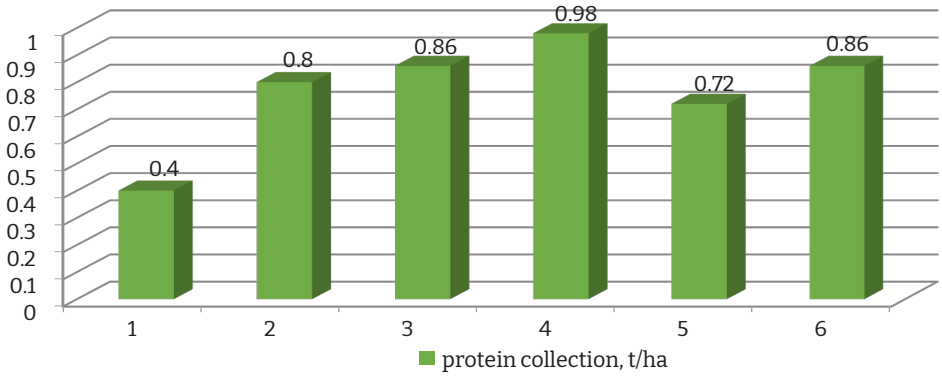

Figure 3. Effect of different fertiliser systems on corn protein yield, t/ha, the average for 2017-2019
Note: Variant 1 – no fertilisers (control); 2 – 60 t/ha of manure; 3 – 60 t/ha of manure+ $N_{40}P_{30}K_{40}$; 4 – 60 t/ha of manure+ $N_{80}P_{60}K_{80}$; 5 – $N_{40}P_{30}K_{40}$; 6 – $N_{80}P_{60}K_{80}$

The collection of crude protein from 1 ha was consistent with the patterns established by its content and yield. When conducting crop rotation without fertilisation, one can expect indicators at the level of 0.40 t/ha, while with systematic fertilisation it is possible to obtain a protein collection at the level of 0.72-0.98 t/ha.

CONCLUSIONS

It was established that during the systematic application of fertilisers in five-field crop rotation under the influence of different systems, the formation of soil backgrounds with different physicochemical properties is observed, the reaction of the soil solution at the introduction of litter manure at a dose of 60 t/ha and against the background of moderate fertiliser rates ($N_{40-80}P_{30-60}K_{40-80}$) contributed to the neutralisation of the soil solution to the values of slightly acidic reaction (pHsal – 5.2-5.5), while in the mineral fertiliser system, the pHsal remained within the medium acid reaction, which indicates the need for its periodic liming once per crop rotation in grey forest soil when only mineral fertilisers are used in the fertiliser system.

In the arable layer (0-20 cm) a trend towards an increase in humus reserves was observed. The most effective was the organic-mineral fertiliser system (12 t/ha of manure + $N_{80}P_{60}K_{80}$) and organic (12 t/ha of manure per 1 ha of crop rotation area), respectively, the total humus content was 1.35 and 1.37% or in percentage terms 25-27% higher compared to the control (without fertilisers) – 1.08 t/ha.

It was found that the content of hydrolysed nitrogen both in the control and fertilised variants at the end of rotation corresponded to the gradation of the level of very low supply, which is associated with a high level of yield and removal of this element by the crop, the content of mobile phosphorus – high level of supply, with an increase of 1.6 times in the organic-mineral fertiliser system $N_{80}P_{60}K_{80}$ against the background of 60 t/ha of manure. With the systematic application of organic and mineral fertilisers for the cultivation of corn for grain, a clear upward trend (up to 61.7 mg/kg of soil depending on fertiliser) of mobile potassium content was observed, which compensates for its constant deficit in the soil, on average, its content fluctuated within the high supply – 120-147 mg/kg of soil.

It is proved that the maintenance of appropriate levels of soil fertility provides conditions for obtaining sustainable yields of winter wheat with relevant quality indexes of the main products. The highest yield levels were achieved by applying the organic-mineral fertiliser system (60 t/ha of manure + $N_{80}P_{60}K_{80}$) – 9.49 t/ha, which is 86% higher than in the control variant (fertilisers), under these conditions the highest yield of crude protein was obtained – 0.98 t/ha.

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Вплив систематичного внесення добрив на родючість ґрунту при вирощуванні кукурудзи на зерно

Анотація. У статті наведено результати досліджень з вивчення впливу систематичного застосування органічних і мінеральних добрив на родючість сірого лісового ґрунту та формування врожаю кукурудзи. Встановлено, що в п'ятипільній сівозміні під час вирощування сільськогосподарських культур відбувалося формування ґрунтових фонів з різними фізико-хімічними властивостями. Внесення підстилкового гною (прямої дії) в дозі 60 т/га на фоні помірних норм добрив ($N_{40-80}R_{30-60}K_{40-80}$) сприяло нейтралізації ґрунтового розчину до значень слабокислої реакції (pHsal -5,2-5,3 од.), тоді як за відсутності гною (мінеральна система удобрення) pHsal залишався в межах середньокислої реакції. Найефективнішою з точки зору гумусового стану ґрунту була органо-мінеральна система удобрення (12 т/га гною + $N_{80}P_{60}K_{80}$) та органічна (12 т/га гною на 1 га сівозмінної площі), відповідно, загальний вміст гумусу становив 1,35 та 1,37% або у відсотковому відношенні на 25-27% більше порівняно з контролем (без добрив) - 1,08 т/га. Оптимізацію показників поживного режиму (гідролізований азот, рухомі форми фосфору і калію) ґрунту в кінці ротації забезпечила органо-мінеральна система удобрення (N100P60K100 проти 60 т/га гною). Найвищу продуктивність кукурудзи на зерно (9,49 т/га) забезпечила органо-мінеральна система удобрення (60 т/га гною + $N_{100}P_{60}K_{100}$), що на 86% перевищує контрольний варіант (без добрив), за таких умов отримано найвищий вихід сирого протеїну - 0,98 т/га

Ключові слова: вміст, азот, фосфор, калій, родючість ґрунту, система удобрення, урожайність, збір білка

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Qualitative characteristics of the fungus *Cyclocybe aegerita* strains 2229, 2230, 2231 IBK under industrial cultivation conditions

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Abstract. Poplar mushroom is characterised by attractive fruiting bodies in terms of appearance and taste. *Cyclocybe aegerita* mushrooms are also known to contain unique substances, including proteins, polysaccharides, and aromatic substances with proven nutritional value and medicinal effects. However, the lack of a sound cultivation technology using available plant material limits the saturation of the domestic market with mushrooms of this species. Three strains of C. aegerita from the IBK National Collection of Agaricale Cultures of the Institute of Ecology and Natural Resources were studied for their potential introduction into commercial culture. It was determined that strains 2230 and 2231 have a vegetation cycle of 42 days compared to 46-64 days for the previously studied strains. The highest yield in the experiment was obtained for strain 2231, which ranged from 217 to 220 g per kilogram of a substrate over three cultivation cycles. The biological efficiency of the strains according to the results of the first wave of fruiting ranged from 20.2 (2229) to 60.4% (2231), which is consistent with the published data of other researchers. The appearance and parameters of the fruiting bodies of the strains, which differed in both the colour of the pileus and the size, were described in detail. Under microclimatic conditions of the experiment, strains 2230 and 2231 had a rich brown colour of pilei, while the formed fruit bodies of strain 2229 were distinguished by a pleasant milky cream colour. The largest fruiting bodies in terms of weight were obtained by cultivation of strain 2229 (7.5 ± 0.4 g), which is on average 2 g higher than the weight of mushrooms of other studied strains. The highest fruiting bodies were discovered in strain 2230 having a height of 91.0 ± 1.8 mm, which also had the widest pilei with a diameter of 29.5 ± 0.9 mm. The largest stem diameter, which reached an average of 10.8 ± 0.3 mm, was detected in the fruiting bodies of strain 2229. This study investigated the variability of morphological traits and identified trends in the number of fruiting bodies of a certain size in the total volume of collected mushrooms, which facilitates the design of packaging and marketing campaigns

Keywords: poplar mushroom, vegetation cycle, yield, biological efficiency, morphological characteristics, artificial cultivation

RELEVANCE

Cyclocybe aegerita (V.Brig.) Vizzini (synonyms *Agrocybe aegerita*, *C. cylindracea*), is commonly known as "black poplar", "pioppino mushroom", or "poplar mushroom". Although this mushroom is quite rare on the Ukrainian market, it is widely cultivated worldwide on substrates made from crop waste and processing of industrial crops as an edible and bioactive substance producer (Chang & Wasser, 2017; Diyabalanage *et al.*, 2008; Huaqi *et al.*, 2004; Muthu *et al.*, 2014). Ordinary consumers value it for its distinctive rich flavour attributed to the presence of 11 aromatic compounds (Surup *et al.*, 2019). The medicinal properties of this variety attract the attention of healthy food connoisseurs and professional manufacturers of bioactive supplements (Diyabalanage *et al.*, 2008; Jing *et al.*, 2018; Landi *et al.*, 2017; Stránský *et al.*, 2010; Zhao *et al.*, 2003). This may be the reason why the current price of poplar mushrooms is 2-6 times higher than the price of champignons, which makes it an attractive crop for mushroom producers (Mulderij, 2016). The species has a high edible and medicinal value, so growing this crop in industrial volumes with a satisfactory quality of fruit bodies will make it possible to replenish the modern market

of functional products with an important source of unique compounds that have a natural antibiotic, Gerontological and antioxidant effect(Jing *et al.*, 2018; Landi *et al.*, 2017; Lo & Cheung, 2005; Stránský *et al.*, 2010).

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The poplar mushroom is a widespread species, which has been recorded on all continents, although it is less common in northern latitudes. It grows on living trees or dead trunks of deciduous trees of the genera *Populus, Salix, Quercus, Ulmus, Acer* and *Robinia* (Frings *et al.*, 2020; Uhart *et al.*, 2008). The international scientific literature contains sufficient evidence on the technical characteristics and morphological features of natural and commercial strains of this species, but data on Ukrainian research on the cultivation of *C. aegerita* is extremely limited. The natural diversity of poplar mushroom ecotypes causes heated discussions about the identification characteristics of this species and introduces significant inconveniences for its introduction into commercial culture. The results of studies on *Cyclocybe aegerita* and *Agrocybe aegerita* have already been unified in scientific databases, as these names are used synonymously. However, after analysing the genetic DNA domains of the fruiting bodies of the genus *Cyclocybe*, scientists combine this species into one group with *C. cylindracea* and argue that their genomes are homogeneous, and therefore that certain phenotypic traits are similar. (Frings *et al.*, 2020; Niveiro *et al.*, 2020; Vizzini *et al.*, 2014.)

Currently, the catalogue of the IBK National Collection of Cultures of Agaricales of the M.G. Kholodny Institute of Botany of the National Academy of Sciences of Ukraine, latest edition (2016), contains 14 strains of *C. aegerita* and 1 strain of *C. cylindracea* (DC.) Vizzini & Angelini, none of which have been used in domestic industrial cultivation, although the results of a study on the biology and physiology of this culture have been published(Bisko *et al.*, 2012; Buhalo *et al.*, 2011; Bisko *et al.*, 2016).

Based on the analysis of recent studies and publications, certain features of the practice of artificial cultivation of *C. aegerita* have been identified:

1) Substrate formulas are based on sawdust, straw, corn cobs, cotton ginning waste, etc.; enriched with bran, phosphorus fertilisers, and gypsum or chalk as a source of calcium (Cheong *et al.*, 2010; Huaqi *et al.*, 2004; Jun-long, 2006; Siwulski *et al.*, 2019);

2) incubation is carried out at the optimum temperature for physiological growth of 25-27°C; according to published data, an increase in temperature to 26°C during the last half of the incubation period increases the yield by 25% (Cheong *et al.*, 2010; Landingin *et al.*, 2020; Xing *et al.*, 2004);

3) the optimal temperature for initiating the formation of fruit bodies is 11-16°C, but for some strains this process occurs at temperatures above 16, sometimes even over 26°C (Fujisawa, 2002; Xing *et al.*, 2004);

4) the yield and quality characteristics of fruit bodies are influenced by the composition of the substrate composition, growing temperature, light intensity, etc., so the advancement of artificial cultivation technology of this species is to identify new, promising strains with high biological efficiency of disposal of available plant residues for industrial cultivation and to determine the optimal microclimate conditions that provide the highest productivity (Bandura *et al.*, 2020; Heo *et al.*, 2019; Isikhuemhen *et al.*, 2009; Uhart *et al.*, 2008).

Purpose of the study**.** From the findings of modern scientific research, it becomes clear that the search for new strains that are promising for commercialisation and biotechnological

use is an urgent issue for practical mushroom growing around the world. Therefore, the purpose of the present study was to determine the qualitative characteristics of three strains grown on substrates from local plant residues at existing farms in Ukraine. The possibility of introducing the strains into industrial production was substantiated based on the results of the analysis of technical characteristics: length of the vegetation cycle, yield, and biological efficiency. Morphological characteristics of fruiting bodies were studied: weight, size, external features of the strains to form characteristics of their quality indicators.

MATERIALS AND METHODS

Cultures of three strains of *C. aegerita* 2229, 2230 and 2231 IBK were obtained from the National Collection of Agaricale Cultures of the M.G. Kholodny Institute of Botany and maintained on a nutrient medium of the following composition: agar-agar – 20 g, malt dextrose – 30 g, fermented dry peptone or dry yeast extract – 2 g; water – up to 1 litre; pH was adjusted to 6.7 ± 0.2 by adding 0.1N KOH solution dropwise. The nutrient medium was sterilised for 35 minutes at a temperature of 121°C (Dudka *et al.*, 1982).

The substrates were sterilised in an industrial autoclave at a temperature of 124 ± 1°C (pressure – 1.4-1.5 atm) in polypropylene bags with four air filters. The bags were filled with a substrate weighing 3120 ± 150 g and wrapped so that during sterilisation steam would enter the substrate. Rapeseed was added to the substrate composition from a mixture of plant residues (barley straw and sunflower husk). The efficiency of this composition for *C. aegerita* 2230 culture was identified in previous studies (Bandura *et al.*, 2018; Bandura *et al.*, 2020; Bandura *et al.*, 2021).

Inoculation of the substrate with 1% (by weight) of grain mycelium and incubation was carried out under aseptic conditions of the controlled microclimate of the laboratory for the production of sowing grain mycelium of LLC SPE "Gribnyi Likar" (Sadove, Melitopol district, Zaporizhzhia o blast). The incubation temperature was 24 ± 1°C; the air humidity in the room was maintained at 67 ± 2%; the CO_2 content was 1200 ± 150 ppm.

The effectiveness of strains and features of cultivation were studied at the facilities of three enterprises: LLC SPE "Gribnyi Likar", LLC "ESMASH-3" and LLC "Fungoterra" (Kyiv) during three growing cycles from February to May 2020 using the same batches of plant material from the 2019 harvest. After incubation for 25 days (first cycle), 28 days (second cycle), and 32 days (third cycle), the packages of 50 pieces of each strain were delivered to the cultivation chambers of the enterprises in closed form and placed on the shelves randomly. An incision was made along the top of the bag and the polypropylene film was turned sideways, forming a narrow hole 10-25 mm wide at a distance of 100-150 mm above the surface of the substrate (Bandura *et al.*, 2021). The microclimate conditions were maintained in accordance with the optimums determined by previous studies: air temperature 16-18°C, humidity 90-93%, carbon dioxide content up to 1300 ppm; lighting at 500-600 lux (Stamets, 2000).

The duration of the vegetation cycle was determined by the number of days from inoculation to the date of harvesting the fruiting bodies.

The yield was calculated by the weight of fresh fruit bodies of the first fruiting wave relative to the initial weight of the substrate (before incubation) for each package.

The biological efficiency of the strains was determined as a percentage by the ratio of the mass of fresh fruit bodies of the first wave to the mass of dry matter in the substrate multiplied by 100.

The morphological parameters of fruiting bodies (FB) were evaluated by determining the

colour and structure of the pilei and stem, the diameters of the pileus and stem, the height of the pedicel and the fruiting body as a whole, and the weight of the fruiting bodies. The variability of traits was determined from samples with at least 40 fruit bodies for each growing cycle with a sample (*p*) for general statistical analysis of at least 100 fruit bodies.

Statistical analysis was performed using Microsoft Office Excel 2016 and the built-in QI Macros 2020 programme. The strains were compared based on the results of descriptive statistics, two-factor and one-factor ANOVA using Tukey and Scheffe tests: *a* – the highest index in the experiment; the same letters indicate no significant difference; different letters indicate significant differences. The smallest significant difference was found using the significance level of $\alpha = 0{,}05$.

RESULTS

Technical indicators. Incubation requires maintaining optimal microclimatic conditions for a certain period of time, so any delay in this process increases energy and labour costs. According to the results of statistical analysis of the date of obtaining fruiting bodies after three cycles of cultivation, no significant effect of prolonging the incubation time on the technical parameters of one strain was found, but significant differences between the strains were determined ($p < 0.0001$) (Table 1).

Table 1. Technical indicators for three cycles of cultivation of *C. aegerita* strains 2229, 2230, and 2231 of the IBK (mean ± s.e.)

Strain	Cycle number (incubation duration, day)	Date of receiving the FB, day	Yield, g/kg of substrate	Biological efficiency, %
2231	1(25)	42.6 ± 0.6^{bc}	$219.5 \pm 11.^{3}a$	59.32 ± 3.04^{a}
	2(28)	42.9 ± 0.4^{bc}	216.8 ± 15.1^{a}	58.54 ± 2.85^{a}
	3(32)	43.3 ± 0.3^{b}	220.1 ± 9.7^{a}	60.42 ± 3.31^{a}
2230	1(25)	41.1 ± 0.3^{c}	215.5 ± 9.5^{a}	57.89 ± 2.37^{a}
	2(28)	42.2 ± 0.5^{bc}	218.1 ± 10.1^{a}	58.89 ± 3.14^{a}
	3(32)	42.7 ± 0.4^{bc}	214.4 ± 9.8^{a}	57.63 ± 1.97^{a}
2229	1(25)	48.7 ± 1.2^{a}	73.2 ± 12.5^{b}	19.87 ± 3.37^{b}
	2(28)	49.2 ± 1.3^{a}	75.1 ± 10.2^{b}	20.2 ± 4.06^{b}
	3(32)	48.8 ± 0.8^{a}	72.8 ± 14.1^{b}	19.78 ± 3.88^{b}
LSD_{05}		2.07	28.7	7.54
p-value		< 0.0001	< 0.0001	< 0.0001

Strain 2229 was characterised by a longer growing cycle, which on average ended 6 days later than in 2231 and 2230. Strain 2230 had the shortest vegetation in the experiment, the fruit bodies of which began to be harvested after 41.1 ± 0.3 days. According to the analysis of the duration of the three cultivation cycles, there was no significant difference between strains 2230 and 2231, and the average result was that the fruiting bodies of these strains were obtained after 42 days from the moment of inoculation. These indicators are significantly lower than the results of Heo *et al.* (2019), who obtained fruiting bodies of the Cham and JBAC15-1 strains at 64 days at a growth temperature of 18°C. However, the indicators of vegetation duration of the studied strains are similar to the results of screening 4 industrial and 8 natural strains of *C. aegerita,* in which the researchers obtained fruit bodies on days 46-64, depending on the nutritional value of the substrates (Heo *et al.*, 2019; Uhart *et al.*, 2008).

Thus, the studied strains are characterised by a short vegetative cycle, and it is not advisable to delay incubation beyond 25 days. However, due to technological needs, such as logistical delays or additional operations to sanitise the growing chambers, incubation can be extended to 8 days without significantly affecting the yield and biological efficiency of the strains.

No differences were found between strains 2230 and 2031 in terms of yield and biological efficiency, while strain 2229 differed significantly ($p < 0.0001$).

The highest yield of 220.1 ± 9.7 g/kg of the substrate in the experiment was found for strain 2231, the lowest at 72.8 ± 14.1 g/kg – for strain 2229. Accordingly, the biological efficacy rates also differed: the highest of 60.42 ± 3.31% was estimated in strain 2231, and the lowest of 9.78 ± 3.88% in strain 2229. The yield of the tested strains is consistent with previously published data. In particular, Li *et al.* (1998) noted that, depending on the nutritional content of the substrates, the yield ranged from 96 g (on plant residues after extraction of medicinal substances) to 113 g of fresh fruiting bodies per kilogram of the substrate when enriched with sawdust with pea waste (10%) (Lee *et al.*, 1998). Isikyumen *et al.* (2009) obtained from 95 to 643 g of fresh fruiting bodies when straw was enriched with grain waste from poultry production, and Yasinska *et al.* cultivating poplar mushroom on sawdust of hardwood trees, obtained from 87 to 395 g/kg (Isikhuemhen *et al.*, 2009; Jasińska *et al.*, 2011). Uhart *et al.* (2008) determined that the biological efficiency of *C. aegerita* is a characteristic feature of the strains and ranges from 21% (strain 313/00) to 70% (621/04) on a wheat straw substrate, which is consistent with results obtained in the present study. However, researchers claim that this figure can rise significantly due to an increase in the nutritional value of the substrate. For example, the biological efficiency of strain 621/04 increased to 140% when 20% soy flour was added to the straw (Uhart *et al.*, 2008).

Thus, strains 2230 and 2231 are promising for introduction into commercial cultivation, but the possibility of improving yields and biological efficiency by optimising the substrate formula and growing conditions requires further study.

Morphological indicators. A prerequisite for the effective introduction of the strain into commercial culture is the study of the morphological characteristics of the shoots or fruit bodies, which is necessary for planning and organising post-harvest activities for the sale or storage of raw materials with appropriate quality. The studied strains exhibited several phenotypic features that allowed them to be distinguished visually (Fig. 1).

2231 2230 2229

Figure 1. Visual appearance of fruiting body growths of the first wave of fruiting of *C. aegerita* strains

In particular, the strains differed in the colour saturation of the pilei, and the surface texture of the pilei and stems, and had some distinctive features of the veil (Table 2).

Table 2. Morphological features of fruiting bodies of *C. aegerita* strains 2231, 2230, 2229 IBK

Features	2231	2230	2229
Pileus shape	Convex, round, becomes flat over time, but the edge is rounded to the stem	Convex, round, becomes flat over time, the edge is thinned, often cracks	Cone-shaped at an early stage, becomes round-convex by the time of technical ripeness, the edge is bent to the stem
Pileus colour	Bright brown, white at the edge, the pileus brightens over time, but with no significant distribution of shades	Dark brown, not divided into shades at the beginning of development, with age from rich dark brown at the apex to almost white along the edge of the pileus	The colour is spread in a ring from dark brown at the top to a bright white skirt at the beginning of development. Changes to the colour of baked milk over time
Texture	Velvety	Velvety	First velvety, then smooth
Stem colour	Milky, with a beige tint over time	Beige	Milky white
Hymenium colour	Beige, darkens to brown over time	Beige, becomes more saturated with age	Milky white, turns beige with age
The presence of a veil	Present, leaves a ring on the stem, often dark in colour	Present, leaves a ring on the stem, which disappears over time	Present, in young fruiting bodies at the edge of the pileus has a skirt like ring of aerial mycelium
Characteristics of scales	There are small scales (less than 1 mm) over the entire surface of the fruiting body	Scales up to 2 mm, in the upper and middle part of the stem, at the base of the stem are practically absent	The scales are small, almost invisible, but create a velvety texture

The shape of the fruit bodies, characteristic features of the pileus attachment to the stem, hymenium location, development and attachment of the veil, and the presence of a ring on the stem after reaching biological maturity did not differ in the studied strains. However, according to the results of statistical analysis, significant differences were found between the weight and size of fruiting bodies (Table 3, Fig. 2).

Table 3. Morphological parameters of fruiting bodies of the first wave of fruiting of *C. aegerita* strains 2229, 2230, 2231 IBK

Strain	FB height, mm	S length, mm	S diameter, mm	P diameter, mm	FB weight, g
2231	$78.2 \pm 2.^{3}b$	68.6 ± 2.1^{b}	8.3 ± 0.3^{b}	28.6 ± 1.2^{a}	5.5 ± 0.6^{b}
2230	91.0 ± 1.8^{a}	$81.1 \pm 1.^{7}a$	7.8 ± 0.2^{b}	29.5 ± 0.9^{a}	4.9 ± 0.3^{b}
2229	74.7 ± 1.5^{b}	64.2 ± 1.4^{b}	$10.8 \pm 0.^{3}a$	25.4 ± 0.7^{b}	7.5 ± 0.4^{a}
LSD_{05}	5.25	4.92	0.77	2.62	1.25
p-value	< 0,0001	< 0.0001	< 0.0001	0.007	< 0.0001

Notes: FB – fruit body, S – stem, P – pileus

Figure 2. Fruiting bodies of *C. aegerita* strains 2231, 2230, 2229 IBK of the first wave of fruiting

The highest height was determined in the fruiting bodies of strain 2230, which differed significantly from other strains in the experiment ($p < 0.0001$). Moreover, the variability of this trait in strain 2230 was the lowest: fruiting bodies ranged in height from 57 mm to 138 mm (Fig. 3).

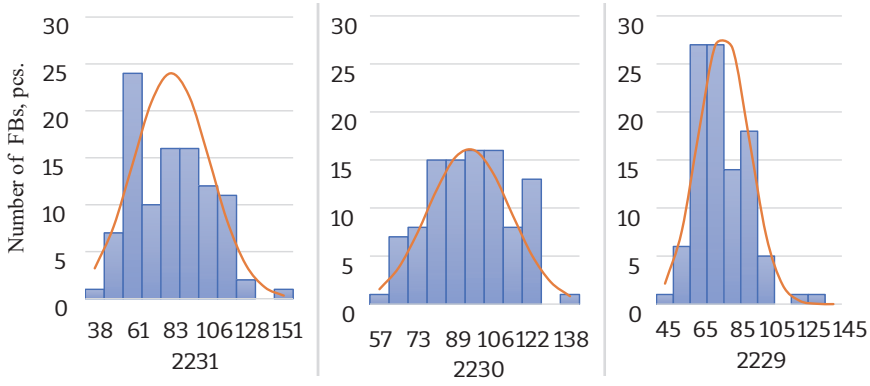

Figure 3. Variation of fruiting body height (mm) of strains in $p = 100$

The coefficient of skewness (C_{sk}) of the sample was -0.006, which indicates a highly symmetrical distribution graph, but the negative sign determines a slight deviation to higher values of the parameter.

The lowest height in the experiment was observed in the fruiting bodies of strain 2229 (74.7 ± 1.5 mm), which did not statistically differ from this characteristic of strain 2231 (78.2 ± 2.3 mm), with the corresponding values of the coefficients: C_{sk} 2229 = 0.97 and C_{sk} 2231 = 0.2 with a tendency to lower values. With a similar pileus thickness, which was 10 ± 1 mm in all strains, the stem length was determinative in the total height of the fruit bodies of the strains, respectively, the largest in strain 2230 (81.1 ± 1.7 mm) and the smallest in strain 2229 (64.2 ± 1.4 mm), and the distributions of samples were similar to the values of FB height.

The results of the analysis revealed that the largest stem diameter of 10.8 ± 0.3 mm was found in the fruiting bodies of strain 2229 (from 6 to 18 mm) with a significant difference from other strains in the experiment. C_{sk} of 2229 was 0.21, whereas C_{sk} 2231 and C_{sk} 2230 had values of 1.51 and 1.12, respectively (Fig. 4).

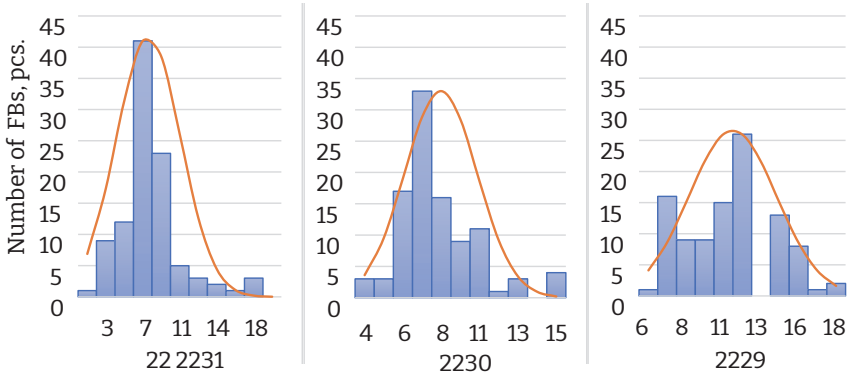

Figure 4. Variability of the stem diameter (mm) of strains by p = 100

Strains 2231 and 2230 had a significantly wider pileus, although the variability of this indicator was higher when compared with strain 2229 (Fig. 5). Strain 2230 had the largest pileus diameter in the experiment (29.47 ± 0.86 mm), strain 2231 did not differ (28.59 ± 1.17), and pileus of strain 2229 was on average 4-5 mm narrower (25.43 ± 0.73).

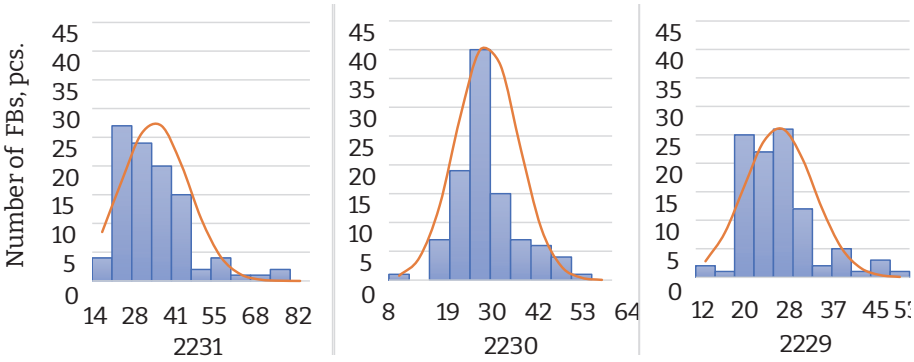

Figure 5. Variability of the pileus diameter (mm) of strains by *p* = 100

The highest average weight of mushrooms was found for strain 2229 (7.46 ± 0.42 g), while the fruiting bodies of strains 2231 and 2230 weighed on average 2 g less (5.53 ± 0.59 and 4.91 ± 0.27, respectively). The variability of this indicator in the experiment was quite high, but for all strains, the asymmetry coefficients were higher than unity (C_{sk} 2231 = 3.34; C_{sk} 2230 = 1.60; C_{sk}2229 = 1.28) (Fig. 6).

This fact indicates a general tendency of the samples to low fetal body weights, which in the experiment ranged from 1 to 43 g.

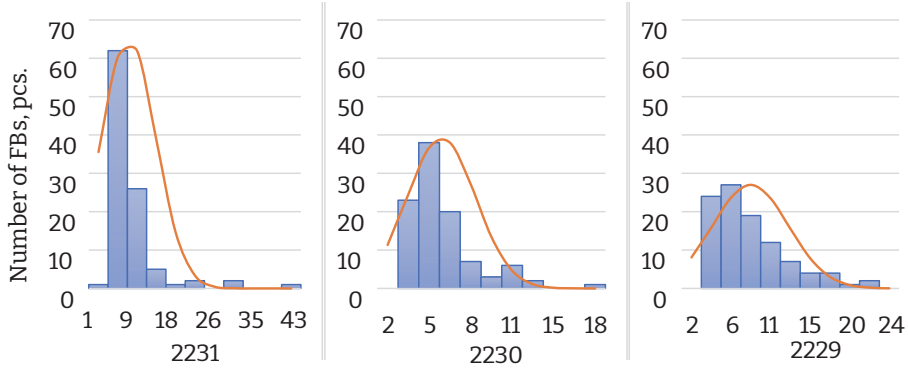

Figure 6. Variation of fruiting body weight (mm) of strains by *p* = 100

The study of trends in the variabilit Variation of fruiting body weight (mm) of strains by *p* = 100 y of morphological traits of strains allows for assessing their stability and, accordingly, makes it possible to predict the total number of fruit bodies of a certain size in the total volume of the crop, which is important for product packaging and marketing operations.

The parameters of the fruit bodies of the studied strains by weight and size coincided with the results of a morphological assessment of strains of other researchers under similar cultivation conditions. In particular, scientists from South Korea received fruiting bodies of *A. cylindracea* strains JBAC15-1 and Cham strains weighing from 3.0 to 5.5 g, respectively. However, they emphasise the dependence of morphological traits on fruiting temperature regimes: an increase in the diameter of the pileus of strain JBAC15-1 from 32.2 ± 0.7 mm when grown at 18°C to 43.0 ± 2.3 mm at 25°C and the height of the stem from 70.1 ± 1.8 (18°C) to 85.1 ± 1.9 (25°C) (Heo *et al.*, 2019).

The determined values of pileus diameters were also similar to the results of the analysis of three strains of *C. aegerita* studied by Argentinian scientists, yielding pileus diameters ranging from the smallest of 26 ± 5 mm (strain 9/98) to the maximum size of 42 ± 8 mm (strain 621/04) (Uhart *et al.*, 2008).

However, the determined average weight and height of the stams of experimental strains were significantly higher than the results of Yasynska *et al.* (2012), who obtained fruiting bodies weighing 3.7 g on a substrate of birch sawdust and 2 g on a substrate of beech sawdust. According to their data, the fruiting bodies reached a maximum height of 48 mm on a substrate made of a mixture of beech and alder sawdust. However, the diameter of the pileus of *A. aegerita* ranged from 27 mm (beech) to 31 mm (birch), which is consistent with the findings of the present study(Jasińska *et al.*, 2012). It is evident that the manifestations of phenotypic parameters are not only related to the unique properties of the strains. The morphological characteristics of fruit bodies are influenced by the technological features of cultivation: the use of substrates of different composition, differences in

microclimatic environment, etc. This conclusion is supported by the findings of Heo *et al.* who emphasise that conditions affect not only the size of the fruit bodies but also the colour of the pileus. Thus, the strain "Cham" at 18°C had a rich dark pileus colour, and at 25°C it was light with a white edge (Heo *et al.*, 2019). Thus, the study of morphological parameters is an important component of the optimisation of cultivation technology and establishment of consumer quality of *C. aegerita* fruiting bodies and requires more thorough research.

CONCLUSIONS

Analysis of technical indicators of cultivation efficiency and morphological features of three strains of *C. aegerita* substantiates the possibility of their introduction into industrial culture. Fungi of strains 2230 and 2231 IBK were obtained on 42 ± 1 day with a yield of 214 to 220 g/kg of substrate on the first wave of fruiting, which is consistent with the results of other researchers. Strain 2229 had a low yield and a prolonged vegetation cycle compared to strains 2230 and 2231 but was distinguished by interesting morphological features: a milky cream colour of the pileus, the highest weight of fruit bodies (7.5 ± 0.4 g) and the thickest stem in the experiment (10.8 ± 0.3). Thus, its appeal makes it possible to increase the selling price, thereby compensating for the reduced efficiency of its cultivation. The variability of the morphological traits of the strains was analysed and the coefficients of sample asymmetry were calculated, which allows predicting the production of fruiting bodies of a certain size. The studied strains have been proven to have stable morphological characteristics, and therefore can be recommended for distribution. However, high results of growing *C. aegerita* strains of foreign origin on substrates with optimised formulas encourage further scientific research to improve the cultivation techniques of this valuable edible and medicinal species.

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Якісна характеристика гриба *Cyclocybe aegerita* штамів 2229, 2230, 2231 ІВК в умовах промислового культивування

Анотація. Тополевий гриб характеризується привабливими плодовими тілами з точки зору зовнішнього вигляду та смакових якостей. Гриби *Cyclocybe aegerita* також відомі тим, що містять унікальні речовини, зокрема білки, полісахариди та ароматичні речовини з доведеною харчовою цінністю та лікувальною дією. Однак відсутність обґрунтованої технології вирощування з використанням доступного рослинного матеріалу обмежує насичення вітчизняного ринку грибами цього виду. Три штами *C. aegerita* з Національної

колекції культур агарицевих грибів Інституту екології та природних ресурсів (ІБК) вивчали на предмет їх потенційного введення в промислову культуру. Встановлено, що штами 2230 і 2231 мають вегетаційний цикл 42 дні порівняно з 46-64 днями у раніше досліджених штамів. Найвищу врожайність в експерименті було отримано для штаму 2231, яка становила від 217 до 220 г на кілограм субстрату протягом трьох циклів культивування. Біологічна ефективність штамів за результатами першої хвилі плодоношення становила від 20,2 (2229) до 60,4% (2231), що узгоджується з опублікованими даними інших дослідників. Детально описано зовнішній вигляд і параметри плодових тіл штамів, які відрізнялися як за кольором ворсинок, так і за розмірами. За мікрокліматичних умов експерименту штами 2230 і 2231 мали насичений коричневий колір піле, тоді як сформовані плодові тіла штаму 2229 вирізнялися приємним молочно-кремовим кольором. Найбільші за масою плодові тіла отримано при культивуванні штаму 2229 (7,5 ± 0,4 г), що в середньому на 2 г перевищує масу грибів інших досліджуваних штамів. Найвищі плодові тіла виявлено у штаму 2230 висотою 91,0 ± 1,8 мм, який також мав найширші пілеї діаметром 29,5 ± 0,9 мм. Найбільший діаметр ніжки, який сягав у середньому 10,8 ± 0,3 мм, було виявлено у плодових тілах штаму 2229. У роботі досліджено мінливість морфологічних ознак та виявлено тенденції щодо кількості плодових тіл певного розміру в загальному обсязі зібраних грибів, що сприяє розробці дизайну пакування та маркетингових кампаній

Ключові слова: тополиний гриб, вегетаційний цикл, урожайність, біологічна ефективність, морфологічні ознаки, штучне культивування

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The Influence of Abiotic Factors on the Growth and Development of Parsnip Plants

Abstract. The main drivers influencing plant growth, yield increase and its quality characteristics are biotic and abiotic factors. Combinations of abiotic stresses, such as drought and heat, have a much greater impact on yields and product quality. Plants' response to these stresses can vary depending on the species and different stages of development. Understanding the mechanisms and how they protect plants from stress has become vital for improving the yield and quality of parsnip products in changing climates. The purpose of the study was to determine the influence of abiotic factors (temperature and precipitation) on the yield, duration of phenological phases of growth and development of plants, the dynamics of leaf and root mass growth of parsnip in the conditions of the Right-Bank Forest-Steppe of Ukraine. The research was carried out in the field experiment of the Department of Vegetable Growing and Closed Ground in the National Research Institute "Fruit and Vegetable Garden" of NUBiP of Ukraine within the conditions of the Right-Bank Forest-Steppe of Ukraine during 2015-2017. The area of the registered plot was 11.3 m^2, and the repetition rate of the experiment is four times. The placement of variants is systematic. The research found that the shortest sowing-emergence period lasted 16 days in the variants sown in the 3rd ten-day period of May and the 1st ten-day period of June. A significant delay of 21 days in this period was noted for sowings from 1st to 3rd ten-day periods of April. The duration of the period from the beginning of root crop formation to bunch ripeness was the shortest when sown in the 1st ten-day period of April – 28 days, and the longest when sown in the 1st ten-day period of June – 51 days. The growing season ranged from 110 to 165 days and was characterised by GDD (>10°C) of 1102.4-1439.0°C and precipitation of 128.1-225.2 mm. After sowing in April, intensive growth of root crops from 2.9 to 3.5 g / day was observed in the second half

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of August. After sowing in May, the greatest increase in root crops from 2.1 to 2.7 g/day was noted in the first half of September. Thus, for sowings in the 1st ten-day period of June, this figure was the highest in the second half of September (1.9 g/day). The variant sown in the 1st ten-day period of April provided a high yield of root crops of 50.3 t/ha, which is 5.3 t/ha or 11.8% significantly more than the control variant. When sowing in the following terms, a significant decrease in yields was observed compared to the control, namely: for 3rd ten-day period of April – by 3.5 t/ha, or 7.7%, for 1st ten-day period of May – by 8.8 t/ha, or 19.6%, for 2nd ten-day periods of May – by 17.4 t/ha, or 38.6%, for 3rd ten-day periods of May – by 23.0 t/ha, or 51.1%, for 1st ten-day period of June – by 31.7 t/ha, 70.6% compared to the control. A strong direct correlation (r = 0.74-0.99) was found between the growing season and yield, root mass, marketability, and biochemical parameters, namely: dry matter, dry soluble matter, sugars, vitamin C. An inverse correlation (r = -0.98) was observed between the duration of the growing season and nitrates. Increasing the growing season by 10 days increases the yield up to 6.9 t/ha, marketability up to 2.7%, root weight up to 31 g, dry matter content up to 0.7%, dry soluble matter up to 0.3%, sugars up to 0.5%, vitamin C up to 0.8 mg/100 g and reduces the nitrate content to 8.4 mg/kg. Leaf area, photosynthetic potential, and net photosynthetic productivity are strongly directly related (r = 0.92-0.98) to yield. For increasing the leaf surface area to 1.0 thousand m^2 the yield is also growing up to 0.7 t/ha. Increasing the photosynthetic potential to 0.05 million m^2 days/ha increases the yield to 0.2-1.2 t/ha. Also, the yield increases to 0.3-0.7 t/ha with an increase in net photosynthetic productivity to 0.05 g/m^2 per day. The molecular knowledge on plant responses to abiotic stress is promising for further study and is likely to advance crop resilience to climate change and increase the economic efficiency of production.

Keywords: parsnip, temperature, precipitation, yield, growth of roots and leaves

RELEVANCE

One of the consequences of global climate change has been a steady decline in the availability and productivity of arable land (Zandalinas *et al.*, 2018). The main factors that have a major impact on plant growth, yield increase and its quality characteristics are biotic and abiotic factors that influence or even determine the final result (Atkinson & Urwin, 2012).

Abiotic factors such as extreme temperatures, droughts, floods, salinity, and heavy metals are among the main factors limiting productivity and crop quality (Kumar, 2020). Combinations of abiotic stresses are known to affect the appearance and spread of biotic stresses such as insect pests, pathogens, weeds, etc. (Ziska *et al.*, 2010; Peters, 2014). Reduced plant growth due to drought or heat is a frequent and widespread phenomenon all over the world. In the case of a combination of both stresses, their effect on crop yields is more severe than that of a particular stress (Sehgal *et al.*, 2017).

The expected temperature changes for the next 30-50 years are assumed to be in the range of 2-3°C. Heat waves or temperature extremes will become more intense, more frequent and last longer than what has been observed in recent years (Hatfield & Prueger, 2015). Extreme temperature periods can have a short duration of a few days with temperature increases of more than 5°C above normal temperatures (Kumudini *et al.*, 2014).

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The temperature response is different for different crop species throughout their life cycle

(Hatfield *et al.*, 2011; Komar *et al.*, 2021). One of the most vulnerable phenological stages to high temperatures is the pollination stage (Shengbao *et al.*, 2020; Bobos, 2019).

Drought stress is associated with a lack of water for the plant, which significantly affects growth, development and yield. There are two types of drought: physical drought (lack of water due to unavailability) and physiological drought (inability of a plant to absorb water from the soil due to various physiological reasons such as salinity, freezing, etc.) (Vadez *et al.*, 2012).

Low temperature (cold stress) also affects the biochemical and physiological activity of plants and, consequently, the yield and quality of products. Low temperature disrupts the membrane structure, protoplasmic flow and causes electrolyte leakage/plasmolysis. Temperature affects mineral absorption, photosynthesis, respiration, and metabolism. Plant response to low-temperature stress is associated with changes in gene transcription associated with the production of several low molecular weight proteins (Yadav *et al.*, 2017).

Water stress includes its deficiency or excessive presence in the environment. Excess water or flooding affects the availability of oxygen to plants, causing low oxygen levels/hypoxia (Sasidharan *et al.*, 2017). Five ERF (ethylene response factor) genes are key regulators of flood resistance and hypoxia tolerance. Studies demonstrate the presence of physiological, genetic, epigenetic and molecular mechanisms in plant resistance to flooding (Gasch *et al.*, 2016).

Parsnips are native to Mediterranean countries (Colombo *et al.*, 2011). Parsnip is a biennial, cold-hardy crop common in many European and Asian countries (Zohary *et al.*, 2012). The origin of plants determines their relation to the environment. Parsnip plants can tolerate frost, although severe cold during the growing season will lead to their death. Parsnip root crops winter well provided there is sufficient snow cover. In spring, the overwintered rosette resumes growth and stem, inflorescence and seeds are formed (Cain *et al.*, 2010).

All parts of the plant contain aromatic essential oils, but the greatest amount of them is found in seeds from 1.5 to 3.6%. Therefore, seeds are characterised by a weak wettable surface, low water retention capacity of the seed coat and increased absorption capacity (Berenbaum & Zangerl, 2006;. Zangerl *et al.*, 2008).

The efficiency of germination is determined by the size and weight of the seeds. Larger and heavier parsnip seeds have high germination energy and produce friendly seedlings, which contributes to high yields. Seed germination is most strongly correlated with seed weight, as filled seeds contain more nutrients for germination (Shankar, 2006; Norden *et al.*, 2009; Kaliniewicz, *et al.*, 2014). The efficiency of seed germination can be improved by mechanical, chemical, physical, and biological methods (Ciupak *et al.*, 2007; Lynikiene *et al.* 2006).

Therefore, understanding the mechanisms and how they protect plants from stress has become vital for improving the yield and quality of parsnip products in changing climates.

The purpose of the study was to determine the influence of abiotic factors (temperature and precipitation) on the yield, duration of phenological phases of growth and development of plants, the dynamics of leaf and root mass growth of parsnip in the conditions of the Right-Bank Forest-Steppe of Ukraine.

MATERIALS AND METHODS

Field studies were conducted in 2015-2017 on the experimental field of the Department of Vegetable Growing and Indoor Ground in the National Forest "Fruit and Vegetable Garden" of NUBiP of Ukraine in the conditions of the Right-Bank Forest-Steppe of Ukraine. The soil of the

experimental plot is soddy-medium podzolized, coarse silt, light loamy.

The following terms of sowing parsnips were studied: 1st ten-day period of April, 2nd ten-day period of April (control), 3rd ten-day period of April, 1st ten-day period of May, 2nd ten-day period of May, 3rd ten-day period of May, 1st ten-day period of June. The size of the experimental plot was 11.3 m^2, the repetition is fourfold. Variants in the experiment were placed systematically. The predecessor for parsnips was cucumber. The studies used the Stimul variety. Sowing was carried out according to the scheme 45x10 cm to a depth of 1.5-2 cm.

The tasks of phenological observations included recording the date of sowing, the emergence of seedlings, the formation of 1-3 true leaves, the beginning of root crop formation, the beginning of bunch ripeness, technical ripeness. The beginning of the phase was recorded when 10% of plants on the plot showed relevant signs, with 75% of plants showing it in mass (Bondarenka & Yakovenka, 2001).

Biometric observations included determining plant height, counting leaf count, leaf and root mass, leaf area, photosynthetic potential, and net photosynthetic productivity.

The dynamics of leaf area were determined by contour scanning of leaves with a further determination of their area using IpSquare 1.9 software. Leaf area per 1 ha of the crop was calculated based on plant density and expressed in thousand m^2 per 1 ha.

To determine the photosynthetic potential of seeding, the assimilation surface of typical plants was regularly measured. Then the leaf area per 1 ha of the crop was calculated by multiplying the average assimilation surface of one plant by the number of plants per 1 ha. The obtained data were placed on graph paper with a time scale on the horizontal axis (abscissa) corresponding to 5 days in 1 cm, leaf area (ordinate axis) – 4000 m^2 in 1 cm. According to this scaling markings showing the results of leaf area determinations were drawn on a millimetre sheet. Connecting the points, a curve was drawn, which showed the progress of leaf area growth per 1 ha during the growing season. Then, the area of the figure (cm^2) bounded by the abscissa axis, derived by a curve and a perpendicular lowered from the end point of the curve to this axis was determined. The photosynthetic potential was determined by the formula:

$$PH_p = S \times O \times A; \quad (1),$$

where PH_p – photosynthetic potential, mln m^2 x days/ha; S – the area of the figure, cm^2; O – the price of one centimetre on the scale along the ordinate axis (4000 m^2); A – number of days.

Net productivity of photosynthesis (NP) was determined by the amount of dry mass growth per day per 1 m^2 of leaf surface according to the formula of Kidd, West and Briggs:

$$PH_{\text{n.pr.}} = \frac{B_1 - B_2}{1/2 \times (L_1 + L_2) \times n}; \quad (2),$$

where $PH_{\text{n.pr.}}$ – net photosynthetic productivity, g/m^2 × day; B_1 and B_2 – dry weight of the sample, at the beginning and end of the accounting period, g; (B_1 - B_2) – dry weight gain for the accounting period; L_1 and L_2 – area of the sample leaves at the beginning and end of the period, cm^2; ½ × (L_1 + L_2) – average area of leaves "working" during the accounting period; n – the number of days in the accounting time interval, days.

GDD > 10°C and precipitation were estimated for the general characterization of heat accumulation and humidification of the territory during the growing season of plants and each of their interphase periods.

Root crops were harvested in each replication by continuous method. They were sorted according to the requirements of DSTU 8473:2015 "Fresh parsnips. Technical conditions". The average weight of marketable roots was determined by the average sample of 5 kg. The number of root

vegetables was calculated and the average weight of marketable root vegetables was determined.

Biochemical studies were carried out in the Ukrainian Laboratory of Product Quality and Safety of the Agro-Industrial Complex of the National University of Bioresources and Nature Management of Ukraine according to standardised methods: the content of dry matter was determined by the thermogravimetric method (DSTU ISO 751:2004), the content of soluble dry matter was determined by the refractometric method (DSTU 8402:2015), total sugar content by Bertrand's method (DSTU 4954:2008), ascorbic acid (vitamin C) by the Murray method (DSTU 7803:2015), and the number of nitrates by ionometric method (DSTU ISO 4948:2008). Statistical processing of the obtained research results was performed by the method of variance and correlation-regression analysis (Kwanchai & Arturo, 1984; Rao, 2007).

RESULTS

Depending on the timing of sowing, the sowing-seedling period ranged from 16 to 21 days and occurred at GDD (>10°C) from 33.4 to 153.7°C and total precipitation from 7.1 to 31.3 mm (Fig. 1). The longest sowing-germination period was observed with the variants sown from 1st to 3rd ten-day periods of April, at later sowing dates this period decreased.

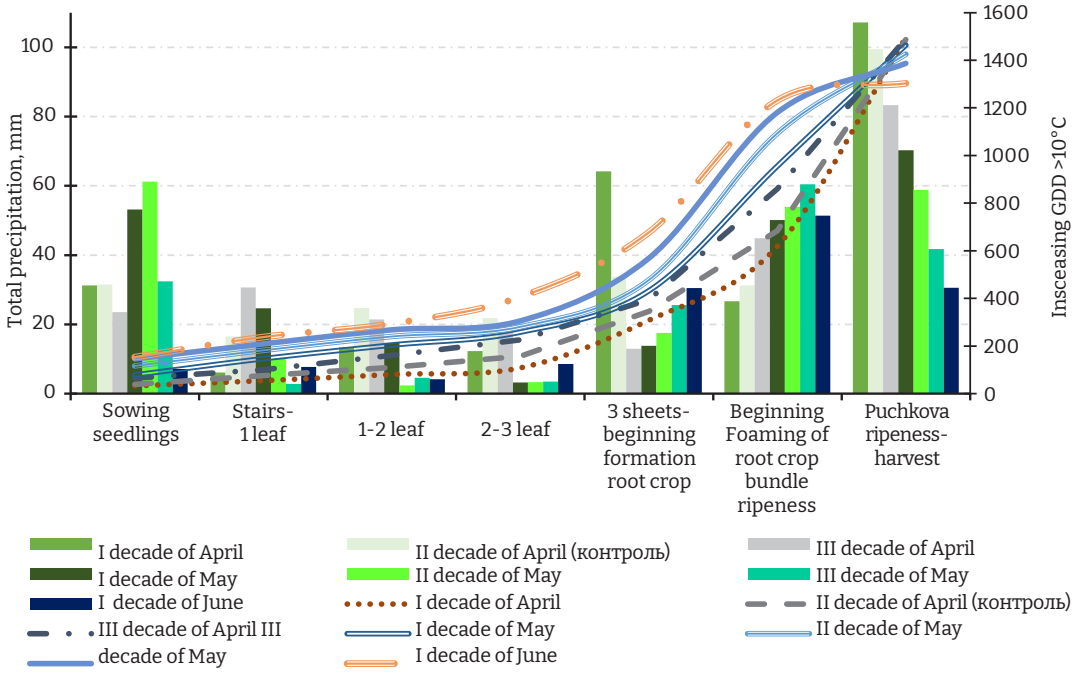

Figure 1. GDD > 10°C and precipitation required for the phenological phases of growth and development of parsnip at different sowing dates (average for 2015-2017)

The appearance of the first true leaf is recorded on 6-9 days after germination. This period was characterised by GDD (> 10°C) ranging from 21.7-84.2°C and precipitation of 2.8-30.7 mm. The phenological phase of the second true leaf is observed 4-8 days after the appearance of the first true leaf. During this phenological phase, the period was characterised by temperatures (>10°C) of 26.1-59.8°C and precipitation of 2.4-24.7 mm.

The period 2-3 of the true leaf lasted 3-8 days and occurred at GDD (> 10°C) of 27.7-112.5°C and precipitation of 3.2-21.8 mm.

The beginning of root crop formation was observed in 17-23 days after the appearance of the third true leaf. During this phenological phase, the period was characterised by GDD (> 10°C) of 168.61-270.8°C and precipitation of 13.0-64.1 mm.

The phenological phase of the beginning of the formation of the root cropbunch ripeness lasted 28-51 days and occurred at GDD (>10°C) of 309.9-616.1°C and precipitation of 26.7-60.4 mm. This period was the shortest for the variants of sowing from 1st to 2nd ten-day periods of April, and at later sowing dates this period increased.

The period of germination-technical ripeness lasted 110-165 days and occurred at GDD (> 10°C) of 1102.4-1439.0°C and precipitation of 128.1-225.2 mm.

Parsnip leaves are a very important organ of the plant, in which organic substances are formed in the process of photosynthesis, due to which the weight of the root crop increases and sugar accumulates.

Leaf weight on July 1 ranged from 11 to 82 g, on August 1 – from 16 to 138, on September 1 – from 52 to 217, and on October 1 – from 63 to 109 g. The maximum growth of leaves with an index of 1.5-4.5 g / day was observed in the second half of August, then the formation of new leaves decreased, and the old ones died off.

On July 1, in the variants sown in April and May, the weight of root crops was 4-37 g. On August 1, the previous figure ranged from 6 to 88 g, on September 1 from 24 to 179 g, and on October 1 from 69 to 236 g.

The maximum growth of root crops in the variants sown in April was observed in the second half of August with an indicator of 2.9-3.5 g/day, sown in May, respectively, in early September – 2.1-2.7 g/day, sown in June, respectively, in the second half of September – 1.9 g/day. The ratio of leaf mass to root crop on July 1 ranged from 2.2 to 2.8, on August 1 – from 1.6 to 2.7, on September 1 – from 1.2 to 2.2, on October 4 – from 0.5 to 0.9.

The variant sown in the 1st ten-day period of April provided a high yield of root crops of 50.3 t/ha, which is 5.3 t/ha or 11.8% significantly more than that of the control variant (Fig. 2). A significant decrease in yield was observed for later sowing in comparison with the control, namely: during the 3rd ten-day period of April – by 3.5 t/ha, or 7.7%, during the 1st ten-day period of May – by 8.8 t/ha, or 19.6%, during the 2nd ten-day period of May – by 17.4 t/ha, or 38.6%, during the 3rd ten-day period of May – by 23.0 t/ha, or 51.1%, during the 1st ten-day period of June – by 31.7 t/ha, 70.6% compared to the control.

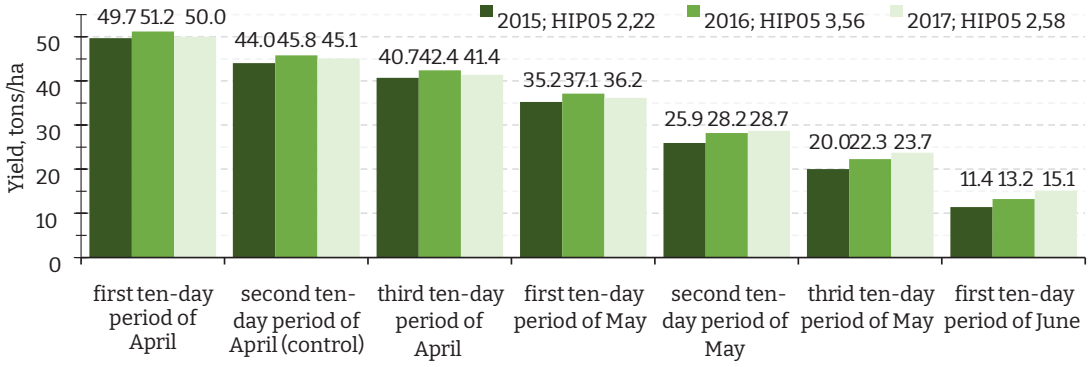

Figure 2. The yield of parsnip roots depending on the time of sowing, tons/ha

A strong direct correlation (r = 0.74-0.99) was found between the growing season and yield, root mass, marketability, and biochemical parameters, namely: dry matter, dry soluble matter, sugars, vitamin C. An inverse correlation (r = -0.98) was observed between the duration of the growing season and nitrates.

Increasing the growing season by 10 days increases the yield up to 6.9 t/ha, marketability up to 2.7%, root weight up to 31 g, dry matter content up to 0.7%, dry soluble matter up to 0.3%, sugars up to 0.5%, vitamin C up to 0.8 mg/100 g and reduces the nitrate content to 8.4 mg/kg.

Leaf area, photosynthetic potential, and net photosynthetic productivity are strongly directly related (r = 0.92-0.98) to yield.

For increasing the leaf surface area to 1.0 thousand $m^2$the yield is also growing up to 0.7 t/ha. Increasing the photosynthetic potential to 0.05 million m^2 days/ha increases the yield to 0.2-1.2 t/ha. Also, the yield increases to 0.3-0.7 t/ha with an increase in net photosynthetic productivity to 0.05 g/m^2 per day.

CONCLUSIONS

An efficient and cost-effective lever for stabilising yields in vegetable production is to use varieties with the high genetic potential of the crop, resistant to diseases and pests and adapted to growing conditions. The creation of a variety, its testing and cultivation are influenced by abiotic factors, and the interaction between these factors and the genetic system of the variety determines its value. The molecular knowledge on plant responses to abiotic stress is promising for further study and is likely to advance crop resilience to climate change and increase the economic efficiency of production. The vegetation period in parsnip lasted 110-165 days and occurred at GDD (>10°C) of 1102.4-1439.0°C and precipitation of 128.1-225.2 mm. Yields at different sowing dates ranged from 13.2 to 50.3 t/ha.

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Вплив абіотичних факторів на ріст і розвиток рослин пастернаку

Анотація. Основними факторами, що впливають на ріст рослин, збільшення врожаю та його якісні характеристики, є біотичні та абіотичні чинники. Поєднання абіотичних стресів, таких як посуха та спека, мають значно більший вплив на врожайність та якість продукції. Реакція рослин на ці стреси може відрізнятися залежно від виду та стадії розвитку. Розуміння механізмів і способів захисту рослин від стресів стало життєво важливим для підвищення врожайності та якості продукції пастернаку в умовах мінливого клімату. Метою дослідження було визначення впливу абіотичних факторів (температури та опадів) на врожайність, тривалість фенологічних фаз росту і розвитку рослин, динаміку наростання листкової та кореневої маси пастернаку в умовах Правобережного Лісостепу України. Дослідження проводили в польовому досліді кафедри овочівництва і закритого ґрунту ННДІ "Плодоовочевий сад" НУБіП України в умовах Правобережного Лісостепу України протягом 2015-2017 рр. Площа облікової ділянки становила 11,3 м^2 , повторність досліду - чотириразова. Розміщення варіантів - систематичне. Дослідженнями встановлено, що найкоротший період сівба-сходи тривав 16 днів у варіантах, де сівбу проводили у 3-й декаді травня та 1-й декаді червня. Значне запізнення на 21 день у цьому періоді було відмічено за сівби з 1 по 3 декаду квітня. Тривалість періоду від початку формування коренеплодів до пучкової стиглості була найкоротшою за сівби в 1-й декаді квітня – 28 днів, а найдовшою за сівби в 1-й декаді червня – 51 день. Вегетаційний період коливався від 110 до 165 днів і характеризувався середньодобовою температурою (> 10 °С) 1102,4-1439,0 °С та кількістю опадів 128,1-225,2 мм. Після сівби у квітні інтенсивний приріст коренеплодів від 2,9 до 3,5 г/добу спостерігався у другій половині серпня. За сівби у травні найбільший приріст коренеплодів від 2,1 до 2,7 г/добу відмічено у першій половині вересня. Так, за сівби в 1-й декаді червня цей показник був найвищим у другій половині вересня (1,9 г/добу). Варіант із сівбою в 1-й декаді квітня забезпечив високу врожайність коренеплодів – 50,3 т/га, що на 5,3 т/га, або на 11,8%, достовірно більше, ніж на контрольному варіанті. За сівби в наступні строки спостерігалося суттєве зниження врожайності порівняно з контролем, а саме: за сівби у 3 декаді квітня - на 3,5 т/га, або на 7,7%, за сівби у 1 декаді травня - на 8. 8 т/га, або 19,6%, за 2 декаду травня – на 17,4 т/га, або 38,6%, за 3 декаду травня - на 23,0 т/га, або 51,1%, за

1 декаду червня - на 31,7 т/га, або 70,6% порівняно з контролем. Встановлено сильний прямий кореляційний зв'язок (r = 0,74-0,99) між тривалістю вегетаційного періоду та врожайністю, масою коренеплодів, товарністю і біохімічними показниками, а саме: суха речовина, суха розчинна речовина, цукри, вітамін С. Зворотний кореляційний зв'язок (r = -0,98) спостерігався між тривалістю вегетаційного періоду та вмістом нітратів. Збільшення вегетаційного періоду на 10 днів підвищує врожайність до 6,9 т/га, товарність до 2,7%, масу коренеплоду до 31 г, вміст сухої речовини до 0,7%, сухої розчинної речовини до 0,3%, цукрів до 0,5%, вітаміну С до 0,8 мг/100 г та знижує вміст нітратів до 8,4 мг/кг. Площа листкової поверхні, фотосинтетичний потенціал та чиста продуктивність фотосинтезу мають сильний прямий зв'язок (r = 0,92-0,98) з урожайністю. Зі збільшенням площі листкової поверхні до 1,0 тис. м2 врожайність також зростає до 0,7 т/га. Збільшення фотосинтетичного потенціалу до 0,05 млн м2 днів/га збільшує врожайність до 0,2-1,2 т/га. Також врожайність зростає до 0,3-0,7 т/га при збільшенні чистої продуктивності фотосинтезу до 0,05 г/м2 на добу. Молекулярні знання про реакцію рослин на абіотичний стрес є перспективними для подальшого вивчення і, ймовірно, сприятимуть підвищенню стійкості сільськогосподарських культур до зміни клімату та економічній ефективності виробництва

Ключові слова: пастернак, температура, опади, врожайність, ріст коренів і листя

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Determination of Pesticide Residues by Chromatographic Methods for Food Safety

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Abstract. The paper presents a methodology for the preparation of samples of oilseeds, lettuce leaves, apple fruits for the study of xenobiotics by chromatographic control of the following chemical groups of pesticides: benzimidazole derivatives, anilinopyrimidine derivatives, bipyridyl derivatives. The following processes are considered: homogenisation of the sample, purification of the extract by solid-phase or liquid-liquid extraction methods, obtaining of plant extract, and obtaining of analytes extract. For fine-grained homogenised samples of sunflower seeds, the optimal raw material-extractant ratio is 1:20, for paste-like homogenised samples of apple fruit – 1:10, and for liquid samples of homogenised lettuce – 1:5. Analysis of the distribution of xenobiotics parameter in the octane/water system (log Pow), reference data on dielectric constant and dipole moment of solvents allowed identifying extractants capable of dissolving and removing xenobiotics from raw materials. It has been found that a mixture of acetonitrile and methanol (4:1) should be used for the extraction of benzimidazole derivatives and anilinopyrimidine derivatives, bipyridyl derivatives are best extracted with methanolic trifluoroacetic acid (9.5:0.5). The content of xenobiotics in extracts obtained from samples artificially enriched with xenobiotics was quantitatively analysed. Xenobiotics were removed from samples of crop products containing traces of fat. The most difficult process of sample preparation is the process of extracting sunflower seeds. The content of xenobiotics in extracts obtained from samples artificially enriched with analytes is affected by the temperature at which the process takes place and the duration of extraction. Based on the chemical composition of the sample matrix and the list of analytes, the conditions of the variable component of the methodology are proposed: obtaining plant extracts under the action of selective solvents, homogenised raw material-solvent with constant stirring of the extraction system at a speed of 180-200 rpm, or when exposed to ultrasonic vibrations at a frequency of 37 kHz from 4 °C to 25 °C for 5-25 minutes. Control of the qualitative and quantitative composition of the studied plant extracts and extracts of analytes was studied by methods of high-performance liquid and gas chromatography (liquid and gas) with mass-selective detectors

Keywords: xenobiotics, pesticides, benzimidazole derivatives, anilinopyrimidine, bipiridium, extracts, chromatography, plant extracts

RELEVANCE

Crop production today is divided into products obtained by classical agricultural technology, which involves the use of agrochemicals and organic products. In the process of cultivation of leaf and stem vegetables, oilseeds, fruits of pome crops, and plant protection products are used, the active components of which are pesticides of different groups (Sekun M.P., 2007). At the same time, residual amounts of pesticides are xenobiotics and, together with man-made pollutants, are normalised in accordance with sanitary and hygienic rules and regulations. Their content is controlled by certain laboratories according to standardised methods (DSanPYN 8.8.1.2.3.4-000-2001). Given the approaches to analysing the content of xenobiotics, there is a need to develop a methodology for the analysis of residual amounts of pesticides of different chemical groups: mixtures of bipyridyl, benzimidazole and anilinopyrimidine derivatives in seeds, green parts and fruits of agricultural crops.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

At the present stage, the methodology for measuring safety indicators in crop production is actively developing. Laboratory monitoring of such xenobiotics as a group of polycyclic aromatic hydrocarbons (PAHs) that can accumulate in oilseeds is considered in many studies (Nesterova L.O., Grybova N.Yu., Khyzhan O.I., 2018; Gribova N.Yu., 2018). The paper describes the study on xenobiotics by high-performance liquid chromatography using a fluorescence detector after the application of solid-phase extraction of analytes. Modernisation of methods for the determination of pesticide residues can include the following stages of sample preparation for research, and instrumental studies of plant extracts and analytes of plant extract purified from co-extractive chemicals. For the isolation of target analytes, specific extractants can be used, along with sorbents, and various physicochemical factors that can change the rheological properties of extraction systems and can intensify the yield of plant homogenised raw materials to the extract of the necessary components (Melo, A. *at al*., 2012; Gribova, N.Y. at al. 2008).

When determining the content of xenobiotics belonging to different groups of pesticides, the most commonly used method is QuEChERS – quick, easy, cheap, effective, rugged and safe (Document No SANCO/12495/2011, 2014). It should be noted that this method of laboratory monitoring does not allow for the removal of xenobiotics, such as surfactant compounds and pesticides of the bipyridyl group – chlormequat, diquat, paraquat. It is known that the spectrum of application of bipyridylium derivatives is sunflower plants, and seed crops of cabbage, table beet, carrot and radish, potato plants, sorghum, clover, fodder beans, soybeans, alfalfa.

Bipyridilium derivatives are quickly absorbed by green parts of the plant, while the contact active ingredient – diquat, quickly turns into hydrogen peroxide, which leads to the destruction of the cell membrane and drying of plants. The active substance decomposes quickly enough in the plant, so the use of diquat is considered relatively safe on seed crops, and on crops intended for food purposes.

The effect of such a drug occurs almost immediately after application, meanwhile, the visual effect of desiccation is already noticeable in 4-7 days. Based on research results (Sekun M.P., 2007) bipiridium derivatives act quickly and, depending on environmental conditions, are consumed in 50-98 hours. Therefore, laboratory monitoring of the content should be conducted with due regard to the timing of the diquat application. State sanitary rules and norms "DSanPiN 8.8.1.2.3.4-000-2001" for diquat set the maximum content of residual amounts in sunflower seeds – 0.5 mg/kg, but at the same time the research methodology is not specified. Therefore, the purpose of the study is to identify the optimal conditions of sample preparation of plant products for the extraction of xenobiotics and establish their qualitative and quantitative content by chromatographic methods of laboratory monitoring.

MATERIALS AND METHODS

The following samples of crop production were used for the research: lettuce leaves of different varieties, oilseeds (sunflower, soybean, flax), fruits of different varieties of apples. A number of parallel laboratory samples were run, of which three samples were subject to artificial enrichment with target xenobiotics. Homogenisation of samples was performed by grinding in a glass of a laboratory homogeniser mill, at temperatures from +4°C to +25°C. To obtain the plant extract, the following chemicals were used (GR): acetone, acetonitrile, methanol, n-hexane, toluene, acids (formic, acetic, trifluoroacetic,

hydrochloric), and isopropanol. These compounds were used as individual extractants or in mixtures, including with deionised water. To buffer the solution of the layer of the homogenized sample under study and in the process of purification of the plant extract, the following chemicals of GR (Guaranteed Reagent) qualification were used: sodium chloride, magnesium sulfate, sodium citrate, aluminium oxide, calcium chloride.

The extraction was carried out in polytetrafluoroethylene tubes, dark glass flasks and polymethyl pentene flasks protected by light-tight covers. During the extraction of analytes, mass transfer was intensified by varying the ratio of raw material-extractant, subjected to stirring, temperature, ultrasonic waves with a frequency of 37 kHz (generated by Advantage Lab**)**. Phase separation of the extraction system was performed using a Thermo Scientific centrifuge, 10 min at 7000 rpm, 4°C. The obtained plant extract was subject to purification from co-extractive compounds by dispersion extraction or liquid-liquid extraction methods using organic solvents and Supelco cartridges filled with mixtures of primary and secondary amines. The concentration of the purified extract was carried out in a rotary evaporator IKA. Analysis of the number of xenobiotics in the obtained solutions was performed by high-performance liquid and gas chromatography using mass spectrometric detectors (HPLC/MS/MS and GC/MS) on Dionex and Agilent chromatographs. The results of analytical signals and spectra of analytes were processed using the calibration dependencies and databases of Cromeleon 6.0 and the installed library of mass spectra (NIST 0.5).

RESULTS AND DISCUSSION

The preparation of a laboratory sample for analysis begins with the same stage for different food groups – homogenisation of the sample. In this study, the sample was homogenised in a beaker mill homogeniser at a speed of 10000 rpm. The obtained homogenised samples differed in their aggregate state due to the different chemical compositions of each matrix: pasty, fine-grained, and liquid. According to the published data on the nutritional value and chemical composition of the sample matrix (Document No SANCO/12495/2011, 2014) the mass fractions of W, % of chemical compounds ($m_{\text{-component}}$) of the matrix were calculated using the formula (1.1) and presented in Table 1:

$$W = \frac{m_{\text{component}}}{m_{\text{homogenized sample}}} \times 100\%. \qquad (1.1)$$

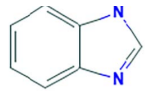
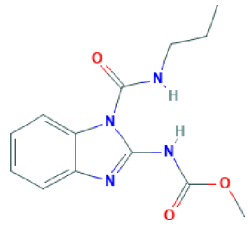
Table 1. Mass fraction of compounds in crop production samples

Sunflower seed kernels	Iceberg lettuce leaves	Fruits of apples with peel
fats 51.46%;	fats 51.46%;	fats 51.46%;
proteins 20.78%;	proteins 20.78%;	proteins 20.78%;
hydrocarbons 10.21%;	hydrocarbons 2.97%;	hydrocarbons 2.97%;
water 4.73%;	water 4.73%;	water 85.56%;
other chemical compounds 12.82%.	other chemical compounds 12.82%.	other chemical compounds 12.82%.

As shown in Table 1, homogenised sunflower seeds contain a significant amount of fat, and the main component of homogenised samples of lettuce leaves and apple fruits is water. Polar and non-polar, proton and antiproton solvents and their mixtures were used in the study. To create more optimal conditions for the extraction of xenobiotics from homogenised raw

materials, additives of organic and mineral acids were used to shift the equilibrium of the dissociation process of ionogenic xenobiotics towards the formation of molecules. The optimal ratio between the extractant and homogenised sample was established by visual analysis of the appearance of the extraction systems and verified by chromatographic analysis of the content of markers (Benomyl, Ciprodinil, Diquat) in plant extracts. For liquid samples of homogenised lettuce leaves, the optimal raw material-extractant ratio is 1:5, for paste-like homogenised samples of apple fruits, the ratio is 1:10, for fine-grained homogenised samples of sunflower seeds – 1:20. At the defined ratios, with constant stirring of 180-200 rpm or under the effect of ultrasonic vibrations with a frequency of 37 kHz in the extraction system, the absence of zones of compression of raw materials is established. This is a necessary condition for the realisation of the mass transfer of xenobiotics from particles of plant material into the hood due to convective diffusion. Xenobiotics belonging to the same chemical group usually differ in the presence of hydrocarbon substituents in the molecule (Table 2). These substitutes can affect the pesticide and toxic properties of the active ingredient of plant protection products, and change the physical and chemical properties (Sekun M.P., 2007). The analysis of the chemical structure of xenobiotics and the distribution parameter of xenobiotics in the octane/water system (log Pow), reference data of dielectric constant and dipole moment of solvents, made it possible to determine and analyse the effect of extractants capable of dissolving and extracting xenobiotics from raw materials, namely acetonitrile, methanol, acetone, n-hexane, toluene, isopropanol, solutions of acetic, formic, trifluoroacetic and hydrochloric acids.

Table 2. Hydrophobicity parameters of some xenobiotics

Name of the chemical compound	Structural formula	log Pow
Benzimidazole		1.3
Benomil		1.4

Analysing the data presented in Table 2, it was assumed that such xenobiotics will concentrate in the organic layer of the extraction system. Extraction of xenobiotics by various extractants and quantitative analysis of xenobiotics in extracts using chromatographic methods (Fig. 1, Table. 3), showed that for the extraction of benzimidazole derivatives and anilinopyrimidine derivatives, it is necessary to use a mixture of acetonitrile with methanol (in a ratio of 4 : 1), bipiridium derivatives are best extracted with a methanol solution of trifluoroacetic acid (at a ratio of 9.5 : 0.5).

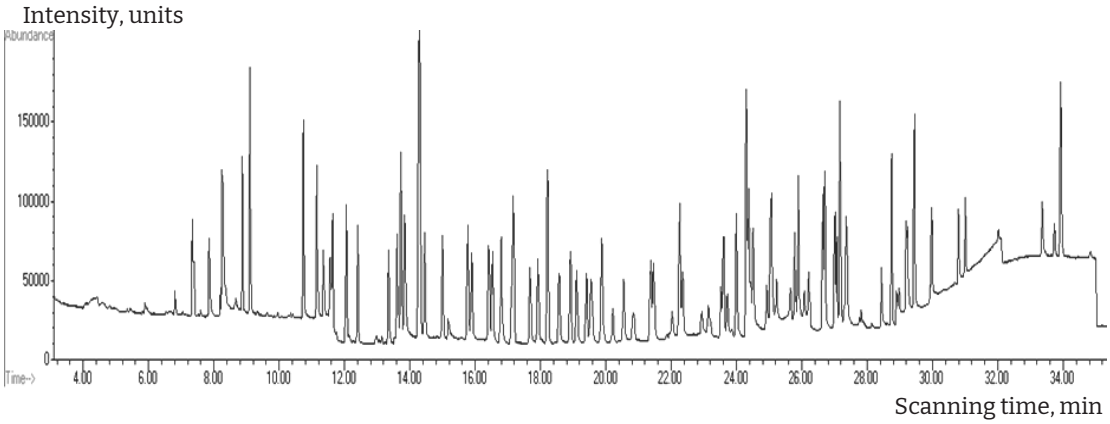


Figure 1. . Chromatogram of plant extract derived by exposure to acetonitrile : methanol (4 : 1) on homogenised apple fruits artificially enriched with xenobiotics (Benomyl, Ciprodinil, Diquat)

Table 3. Quantitative analysis of xenobiotic content in extracts obtained from samples artificially enriched with xenobiotics

Marker name	Extractant	Introduced, µg/kg	Determined, µg/kg	Removals, %
Sunflower seeds				
Benomil	mixture of acetonitrile and methanol (4:1)	0.50 ± 0.01	0.41 ± 0.03	82.0 ± 6
Ciprodinil		0.50 ± 0.01	0.40 ± 0.03	80.0 ± 6
Diquat	methanol solution of trifluoroacetic acid	0.50 ± 0.01	0.43 ± 0.03	86.0 ± 6
Lettuce leaves				
Benomil	mixture of acetonitrile and methanol	0.50 ± 0.01	0.49 ± 0.01	98.0 ± 2
Ciprodinil		0.50 ± 0.01	0.49 ± 0.02	98.0 ± 4
Diquat	methanol solution of trifluoroacetic acid	0.50 ± 0.01	0.51 ± 0.03	102.0 ± 6
Apple fruits				
Benomil	mixture of acetonitrile and methanol	0.50±0.01	0.48±0.01	96.0±2
Ciprodinil		0.50±0.01	0.49±0.02	99.0±4
Diquat	methanol solution of trifluoroacetic acid	0.50±0.01	0.47±0.02	94.0±4

Peaks were identified from the library of mass spectra by comparing two parameters: the retention time of the xenobiotic peak and the retention time of the analytical standard peak, the values of characteristic ions of xenobiotics and the corresponding values of analytical standards. Quantitative analysis was carried out by calibration dependences, the mean value and error of he value obtained during the measurement were calculated using the Exel programme.

Table 3 shows that xenobiotics were completely removed from samples of crop products

containing trace amounts of fat (Table 2). The most difficult from the point of view of conducting the process of sample preparation for research and according to the percentage of extraction of xenobiotics (Table 3), is the process of obtaining a plant extract from sunflower seeds. The percentage of isolated xenobiotics from sunflower seeds is less than the percentage of the same markers extracted from lettuce leaves and apple fruits. However, the process of performing sample preparation of sunflower seeds is satisfactory, since the established average percentage of extraction of an artificially introduced xenobiotic is more than 80%. The content of xenobiotics in extracts obtained from samples artificially enriched with analytes (Table 3) is affected by the temperature at which the process takes place and the duration of the extraction. Optimal conditions are the temperature from 4°C to 25°C and exposure to the extractant for 5-25 minutes.

CONCLUSIONS

Analysis of the quantitative and qualitative content of xenobiotics in plant extracts and extracts purified from coextractive substances made it possible to establish the optimal conditions for the variable component of the methodology for preparing samples of crop production to the stage of determining the content of xenobiotics by chromatographic methods of laboratory control. Optimal extractants are mixtures of acetonitrile with methanol (4:1) and a mixture of methanol with trifluoroacetic acid (9.5:0.5). The ratio of components of the extraction system varies depending on the aggregate state of the homogenised sample. It was found that the optimal ratio of raw materials and extractant for sunflower seeds is 1:20, for apples – 1:10, for lettuce leaves – 1:5. Extraction is carried out under conditions of constant stirring of the extraction system at a speed of 180-200 rpm, or by exposure to ultrasonic vibrations at a frequency of 37 kHz at a temperature from 4°C to 25°C for 5-25 min.

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Визначення залишкових кількостей пестицидів хроматографічними методами для безпечності харчових продуктів

Анотація. У статті представлено методику підготовки зразків насіння олійних культур, листя салату, плодів яблуні для дослідження ксенобіотиків методом хроматографічного контролю наступних хімічних груп пестицидів: похідні бензімідазолу, похідні анілінопіримідину, похідні біпіридилу. Розглядаються наступні процеси: гомогенізація зразка, очищення

екстракту методами твердофазної або рідинно-рідинної екстракції, отримання рослинного екстракту, отримання екстракту аналітів. Для дрібнозернистих гомогенізованих зразків насіння соняшнику оптимальне співвідношення сировина-екстрагент становить 1:20, для пастоподібних гомогенізованих зразків плодів яблук - 1:10, а для рідких зразків гомогенізованого салату - 1:5. Аналіз розподілу параметра ксенобіотиків у системі октан/вода (log Pow), довідкових даних щодо діелектричної проникності та дипольного моменту розчинників дозволив визначити екстрагенти, здатні розчиняти та вилучати ксенобіотики із сировини. Встановлено, що для екстракції похідних бензімідазолу та анілінопіримідину доцільно використовувати суміш ацетонітрилу та метанолу (4:1), біпіридильні похідні найкраще екстрагуються метанол-трифтороцтовою кислотою (9,5:0,5). Вміст ксенобіотиків в екстрактах, отриманих із зразків, штучно збагачених ксенобіотиками, було проаналізовано кількісно. Ксенобіотики вилучали із зразків рослинницької продукції, що містять сліди жиру. Найскладнішим процесом пробопідготовки є процес екстрагування насіння соняшнику. На вміст ксенобіотиків в екстрактах, отриманих із зразків, штучно збагачених аналітами, впливає температура, при якій відбувається процес, і тривалість екстракції. Виходячи з хімічного складу матриці зразків та переліку аналітів, запропоновано умови проведення варіативної складової методики: отримання рослинних екстрактів під дією селективних розчинників, гомогенізованої системи сировина-розчинник при постійному перемішуванні екстракційної системи зі швидкістю 180-200 об/хв, або при дії ультразвукових коливань з частотою 37 кГц від 4 °С до 25 °С протягом 5-25 хвилин. Контроль якісного та кількісного складу досліджуваних рослинних екстрактів та екстрактів аналітів вивчали методами високоефективної рідинної та газової хроматографії (рідинної та газової) з мас-селективними детекторами

Ключові слова: ксенобіотики, пестициди, похідні бензімідазолу, анілінопіримідин, біпіридій, екстракти, хроматографія, рослинні екстракти

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