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E-mail: info@agriculturalscience.com.ua
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Editors Office Address:

National University of Life and Environmental Sciences of Ukraine

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E-mail: info@agriculturalscience.com.ua

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Oleksandr Derevianko^{1*}, Nazanin Maherramzade², Stanislav Derevianko³

¹National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

²T. H. Shevchenko National University "Chernihiv Colehium"
14013, 53 Hetman Polubotko Str., Chernihiv, Ukraine

³Institute of Agricultural Microbiology and Agro-industrial Manufacture of NAAS of Ukraine
14027, 97 Shevchenko Str., Chernihiv, Ukraine

Evaluation of the biological effect of Zn nanocarboxylates and MoS₂ nanoparticles on corn sprouts (*Zea mays* L.)

Abstract. If it is necessary to reduce the anthropogenic impact on agroecosystems in conditions of constant increase in the cost of resources – improving the technology of growing corn through the use of nanotechnologies is one of the prerequisites for increasing the yield of crops and their profitability. In this regard, the purpose of the study was to investigate the biological activity of Zn nanocarboxylates and MoS₂ nanoparticles at different concentrations for the germination, growth, and development of corn seedlings. An experiment was conducted on corn sprouts to determine the effect of Zn and MoS₂ nanoparticles. The germination rate and germination energy of seeds under the action of nanoparticles were determined in accordance with the requirements of the state standard DSTU 4138-2002. The study results were analysed by generally accepted statistical methods. It was established that MoS₂ nanoparticles when diluted at 1:10,000 (at a concentration of 700 mcg/l) show biological activity and cause an increase in the length of leaf blades and the length of the roots of corn seedlings by 35.0% and 100.0%, respectively. At other concentrations (1:100; 1:1,000) of Zn and MoS₂ nanoparticles, no significant effect on the size of leaf blades and roots was observed. According to the results of the Mana-Whitney test, in all variants, with the exception of the action of MoS₂ nanoparticles in a 1:10,000 dilution, the significance level of changes was not sufficient. Only in the variant with MoS₂ at 1:10,000 dilution, an increase in root length was statistically significant. There was no statistically significant effect in all the studied variants on the germination energy and laboratory germination of maize seeds. The practical value of the study is to assess the effect of drugs (Zn nanocarboxylates and MoS₂ nanoparticles) for foliar top dressing, a wide range of which is offered to agricultural producers, selection of effective concentrations for the growth, development, and yield of corn per grain

Keywords: root length, leaf blade length, laboratory germination, germination energy, nanotechnology

INTRODUCTION

Corn is one of the main grain crops grown in Ukraine. In 2021, the sown area of corn was 5,522.4 thousand hectares, and the yield of grain was 42,109.85 thousand tonnes [1], so improving the technology of growing corn and increasing its yield is an important task of agricultural science.

In the last decade, the effect of nanoparticles (NP) of various substances and various nanomaterials (NM)

on corn plants has been actively studied in the world and in Ukraine in particular [2-4]. Studies on the effect of NPs and other NMs on corn concern a wide range of issues: the effect of nanoparticles on germination energy and seed germination [5-7], morphometric [7-9], physiological, biochemical, and biophysical [3; 5; 9] plant parameters, mechanisms of NP uptake and transport by

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*Corresponding author

plants [3; 4], phytotoxicity of NPs [6] and, importantly from a practical standpoint, their impact on corn yield [7; 8; 10]. The global scientific community widely discusses the significant prospects of introducing nanotechnologies to increase the corn yield [7; 8; 11].

NPs and other NMs are known to affect the germination energy and germination rate of maize seeds. Thus, niobium-containing nanocomposites increase the germination energy and laboratory germination of seeds of the Kharkivskiyi 340 MV corn hybrid by an average of 10% [1], and γ - Fe_2O_3 nanoparticles at a concentration of 20 mg/l, significantly increase the germination index by 27.2% [3]. At the same time, CuO [4], Si [5], TiO_2 , SiO_2 , CeO_2 , Fe_3O_4 , Al_2O_3 , ZnO, and CuO [6] do not have a statistically significant effect on the germination parameters of maize seeds. Another study found that Fe nanoparticles increase corn seed germination by 7.89-12.25% at concentrations of 3-5 mg/l; while Co nanoparticles increase germination by 4.86% at concentrations of 3 mg/l, but reduce by 1.68-7.77% at concentrations of 4-5 mg/l; Cu nanoparticles do not significantly affect germination at concentrations of 3 mg/l, increase germination by 25.74% at concentrations of 4 mg/l, and reduce by 13.43% at concentrations of 5 mg/l [7].

NPs and NMs affect the morphometric parameters of maize plants at different stages of development. Thus, niobium-containing nanocomposites increase the length of seedlings of the Kharkivskiyi 340 MV corn hybrid and their root system by 50-70% [2]. γ - Fe_2O_3 nanoparticles at a concentration of 20 mg/l significantly increase the length of corn roots by 11.5%, but at concentrations of 50 and 100 mg/l, it is significantly reduced by 13.5 and 12.5%, respectively [3]. CuO nanoparticles at concentrations of 10 and 100 mg/l significantly reduce the length of the root system of maize seedlings by 55-85% [4]. Under the conditions of vegetation experiment, Si nanoparticles increased the length of maize roots during the first 20 days of observation, but in the future, the growth parameters for the action of Si NPs did not differ from the control [5]. Another study showed that CU nanoparticles increase the length and dry weight of the root system of maize seedlings [7]. In the conditions of field experiment, it was found that during the treatment of ZnO nanoparticles, the height of corn plants was significantly higher than the control by 20.90% at the 60th day after sowing and by 16.11% at the time of harvesting [8].

Some researchers note the toxic effects of NPs on maize plants. It was found that CuO and ZnO nanoparticles at concentrations of 2,000 mg/l significantly inhibit the growth of the root system of maize seedlings, reducing its length by 95.73% and 50.45%, respectively. ZnO, Al_2O_3 , and CuO nanoparticles have a dose-dependent effect on the length of the root system of maize seedlings, while Al_2O_3 NPs have the lowest toxicity [6]. It is worth noting that the same study found that CuO nanoparticles are not toxic to corn seedlings at a concentration of 10 mg/l [6], which means that the toxicity of NPs of many

substances strongly depends on their concentration and with correctly selected concentrations, NPs can be quite safe for use in various sectors of the national economy, including agronomy.

NPs and NMs affect corn yield and structure in field experiments. Thus, Cu nanoparticles increase the weight of 1,000 seeds of the LVN10 corn hybrid by 4%. The yield of the VN8960 hybrid corn under Cu NP treatment was 8,589 t/ha, while the control crop was 7,030 t/ha [7]. Foliar application of ZnO nanoparticles significantly increases the average number of cobs per plant by 7.51%, the average length of the cob by 18.58%, the average girth of the cob by 12.61%, the yield of cobs by 16.85%, and the weight of stubble by 16.85% [8]. It is also established that the TiO_2 nanoparticles increase the average number of seeds on the cob and grain yield. With TiO_2 nanoparticles, an almost linear relationship was established between these indicators with a correlation coefficient $r = 0.97$ [11].

Many Ukrainian researchers note the biological activity of nanoparticles in stimulating plant growth and develop nanobiological fertilisers. [12]. A positive effect on the sowing qualities of leguminous seeds of pre-sowing treatment with the microelement preparation Avatar-1, immunomodulators (growth stimulator) Iodis concentrate and Iodis concentrate + Se and colloidal solutions of NP metals was established. Significantly, by 4-8%, the use of the immunostimulator Iodis concentrate + Se increases the laboratory germination of seeds. The use of Mo and Mn nanoparticles contributes to improving the sowing qualities of seeds. It was found that the laboratory germination rate of soy seeds increases by 5%, beans – by 7%, lentils – by 12%. Pre-sowing treatment of legume seeds with NP solutions of Ce, Ge, Se, and Cu leads to inhibition of germination [13].

The authors of the study previously proved the growth-regulating activity of the composition of Se and I nanoparticles on winter wheat seedlings [14]. The biological activity of Ni nanoparticles was studied in [15]. In addition, it has been experimentally proven that Zn NPs, the composition of Se and I NPs, and the microelement preparation Avatar-2 Protection not only increase potato productivity and marketability [16], but also can significantly reduce the degree of potato damage by infectious diseases and the frequency of their detection [17]. However, the biological activity of most known nanoparticles in relation to maize plants has not been investigated.

The purpose of the study is to assess the effect of Zn nanocarboxylates obtained by ablation and MoS_2 nanoparticles, obtained by biological synthesis at different concentrations for the length of leaf blades and roots, and the germination energy of corn seedlings.

MATERIALS AND METHODS

The study was conducted in 2021-2022 in the laboratory "Soil Fertility and Protection" of the Department of Soil Science and Soil Protection named after Prof. M.K. Shykula of the National University of Life and Environmental Sciences

of Ukraine and in the laboratory “Virology” of the Institute of Agricultural Microbiology and Agroindustrial Production of NAAS. The study uses zinc nanocarboxylates (colloidal solutions of Zn nanoparticles stabilised by citrate anions, which are obtained by erosion-explosive dispersion [18]), obtained from LLC “Nanomaterials and nanotechnologies” from Doctor of technical sciences V.G. Kaplunenko, and MoS₂ nanoparticles obtained by biological synthesis, obtained from LLC “Scientific and technical centre Bioquant”. The concentration of Zn nanoparticles was 4 g/l, MoS₂ nanoparticles – 7 g/l. Nanoparticle dilutions 1:100, 1:1,000, 1:10,000 in sterile distilled water were prepared before use.

The study of the biological activity of NPs was carried out using the hybrid corn Limagrain LG 30.271, FAO 260, weight of 1,000 seeds – 310 g. Before laying the experiment, the seeds were washed.

Corn seeds (72 units for each variant) were washed and soaked for 5 hours in warm water. Then, in petri dishes, 18 seeds were laid out on filter paper with the plant embryo to the top and sprouted at a temperature of 25-26°C. The repetition was fourfold. Seedlings with a root length of 1-2 cm were used for further experiments.

To determine the effect of NPs, the root tips (the growth point in the meristematic zone) of maize seedlings were placed for 1 hour in the corresponding NP dilutions. Control seedlings were placed in water. After that, the sprouts were again placed in petri dishes on wet filter paper and placed in a thermostat at a temperature of 25-26°C. After 24 hours, the length of leaf blades and roots was measured in control and experimental variants [19]. The obtained data were processed statistically [20]. The experiment scheme is shown in Table 1.

Table 1. Experiment scheme

Variant	Repeatability	Number of seeds in repetition
Control (H ₂ O)	Fourfold	18
Zn nanoparticles, dilution 1:100	Fourfold	18
Zn nanoparticles, dilution 1:1,000	Fourfold	18
Zn nanoparticles, dilution 1:10,000	Fourfold	18
MoS ₂ nanoparticles, dilution 1:100	Fourfold	18
MoS ₂ nanoparticles, dilution 1:1,000	Fourfold	18
MoS ₂ nanoparticles, dilution 1:10,000	Fourfold	18

Seed germination and germination energy under the action of Zn and MoS₂ nanoparticles were determined in accordance with the requirements of the state standard DSTU 4138-2002 [21]. Statistical analysis was performed in StatSoft STATISTICA 12 software suite. Nonparametric statistical methods were used for the analysis. In the analysis of descriptive statistics, the median, upper and lower quartiles, and interquartile spread were calculated; the statistical significance of the results

was determined by the Mann-Whitney U test [20].

RESULTS AND DISCUSSION

When comparing corn sprouts of the control group with experimental ones, it was found that under the action of Zn and MoS₂ nanoparticles in variants with Zn 1:100, Zn 1:1,000, 1:10,000, MoS₂ 1:100, and MoS₂ 1:1,000 the length of leaf blades was 40.0, 60.0, 40.0, 60.0, and 30.0% less than in the control, respectively (Table 2).

Table 2. Effect of Zn and MoS₂ nanoparticles on the length of the leaf blades of corn sprouts (cm)

Variant	Average length of leaf blades, cm	Δ, %	Lower quartile	Upper quartile	Interquartile range	Significance, according to the Mann-Whitney U test, P
H ₂ O	1.0	0	0.30	1.50	1.20	–
Zn 1:100	0.60	-40.00	0.40	1.40	1.00	>0.96
Zn 1:1,000	0.40	-60.00	0.30	1.30	1.00	>0.50
Zn 1:10,000	0.60	-40.00	0.30	1.00	0.70	>0.51
MoS ₂ 1:100	0.40	-60.00	0.30	0.80	0.50	>0.12
MoS ₂ 1:1,000	0.70	-30.00	0.40	1.50	1.10	>0.93
MoS ₂ 1:10,000	1.35	+35.00	0.65	2.00	1.35	<0.05

In a dilution of 1:10,000 MoS₂ NPs, the length of the leaf blades of maize seedlings was 35.00% longer than in the control (Table 2).

According to the Mann-Whitney test, in the Zn 1:100, Zn 1:1,000, Zn 1:10,000, MoS₂ 1:100 and MoS₂ 1:1,000 variants,

the changes did not have a sufficient level of statistical significance. That is, at these concentrations of Zn and MoS₂ nanoparticles, it cannot be reliably stated that they are toxic to corn sprouts. In the MoS₂ 1:10,000 variant, an increase in leaf blade length was statistically significant (Table 2).

It was found that in the Zn 1:1,000 and MoS₂ 1:100 variants, the root length was 30.00 and 20.00% less than in the control, respectively. In Zn 1:100 and Zn 1:10,000,

MoS₂ 1:1,000 and MoS₂ 1:10,000 variants, the root length was greater than in the control by 20.0 and 50.0; 40.0 and 100.0%; respectively (Table 3).

Table 3. Effect of Zn and MoS₂ nanoparticles by the length of the roots of corn sprouts (cm)

Variant	Average root length, cm	Δ, %	Lower quartile	Upper quartile	Interquartile range	Significance, according to the Mann-Whitney U test, P
H ₂ O	0.50	0	0.40	1.00	0.60	-
Zn 1:100	0.60	+20.0	0.60	1.00	0.40	>0.57
Zn 1:1,000	0.35	-30.0	0.20	1.00	0.80	>0.34
Zn 1:10,000	0.75	+50.0	0.35	1.00	0.65	>0.98
MoS ₂ 1:100	0.40	-20.0	0.20	0.80	0.60	>0.08
MoS ₂ 1:1,000	0.70	+40.0	0.30	1.00	0.70	>0.61
MoS ₂ 1:10,000	1.00	+100.0	0.50	2.00	1.50	<0.02

According to the Mann-Whitney test in all variants except MoS₂ 1:10,000, the significance level of the changes was not sufficient. Only in the MoS₂ 1:10,000 variant, an increase in root length was statistically significant (Table 3). In the Zn 1:100, Zn 1:10,000, and Zn 1:10,000 variants, a

decrease in seed germination energy was observed by 19.44, 22.22, and 30.56%, respectively (Table 4). In variants of MoS₂ nanoparticles in dilutions of 1:100, 1:1,000, and 1:10,000, an increase in seed germination energy was observed by 8.33; 2.78, and 2.78%, respectively (Table 4).

Table 4. Energy of corn seed germination under the action of Zn and MoS₂ nanoparticles (%)

Variant	Average germination energy, %	Δ, %	Lower quartile	Upper quartile	Interquartile range	Significance, according to the Mann-Whitney U test, P
H ₂ O	50.00	0.00	38.89	66.67	27.78	-
Zn 1:100	30.56	-19.44	22.22	36.11	13.89	>0.05
Zn 1:1,000	27.78	-22.22	19.44	41.67	22.22	>0.11
Zn 1:10,000	19.44	-30.56	16.67	38.89	22.22	>0.11
MoS ₂ 1:100	58.33	+8.33	44.44	63.89	19.44	>0.88
MoS ₂ 1:1,000	52.78	+2.78	47.22	55.56	8.33	1.00
MoS ₂ 1:10,000	52.78	+2.78	47.22	58.33	11.11	>0.88

Thus, the Zn and MoS₂ nanoparticles do not affect the germination energy of corn seeds.

In experimental versions for processing corn seeds by breeding Zn nanoparticles 1:100, 1:1,000, 1:10,000, there

was a decrease in laboratory similarity by 13.89, 11.11, and 19.44%, respectively. For action of MoS₂ nanoparticles for the same dilutions, an increase in germination was obtained by 11.11; 8.33, and 13.89%, respectively (Table 5).

Table 5. Laboratory germination of corn seeds by the action of Zn and MoS₂ nanoparticles (%)

Variant	Average germination rate, %	Δ, %	Lower quartile	Upper quartile	Interquartile range	Significance, according to the Mann-Whitney U test, P
H ₂ O	58.33	0.00	47.22	75.00	27.78	-
Zn 1:100	44.44	-13.89	38.89	50.00	11.11	0.20
Zn 1:1,000	47.22	-11.11	33.33	55.56	22.22	>0.34
Zn 1:10,000	38.89	-19.44	30.56	61.11	30.56	0.20
MoS ₂ 1:100	69.44	+11.11	61.11	77.78	16.67	>0.48
MoS ₂ 1:1,000	66.67	+8.33	61.11	77.78	16.67	>0.48
MoS ₂ 1:10,000	72.22	+13.89	63.89	80.56	16.67	>0.48

According to the Mann-Whitney U test in all the studied variants for the use of Zn and MoS₂ nanoparticles, the changes did not have a sufficient level of statistical significance. That is, at these concentrations of Zn and MoS₂ nanoparticles it cannot be said that they affect the laboratory germination of corn seeds (Table 5).

As a result of the conducted studies, it was established that the MoS₂ NPs in a dilution of 1:10,000 (at a concentration of 700 mcg/l) show biological activity and cause a statistically significant increase in the length of the leaf blades of corn seedlings by 35.0% and the length of the roots by 100.0%. Using Zn and MoS₂ nanoparticles at other concentrations, an increase in the length of leaf blades and roots was not detected, which is consistent with the results obtained by other scientists [7]. There was no statistically significant effect in all the studied variants on the germination energy and laboratory germination of maize seeds.

According to the results of studies by other researchers, nanoparticles of various elements, or nanoparticle compositions at different concentrations can be toxic to seedlings of seeds of different crops [7], reducing the size of leaf blades and roots, stimulating the growth and development of seedlings, increasing, reducing the energy of germination and seed germination, or not having a significant effect on these indicators. CuO nanoparticles at a concentration of 100 mg/l did not affect germination, but suppressed the growth of maize seedlings [4]. It was found that the phytotoxicity of ZnO, Al₂O₃, and CuO nanoparticles in the range from 25 to 2,000 mg/l depended on the nanoparticle concentration [6]. Thus, both the results of previous studies and the materials presented in the paper strongly indicate a dose-effect relationship for the studied NPs.

The dependence of phytotoxicity on the method of obtaining nanoparticles is established. It is known that under the action of Se nanoparticles obtained by ablation, the length of winter wheat leaf blades decreased by 15.84%, while under the action of Se Bio nanoparticles obtained by biosynthesis in the same concentration, their length increased by 40.32% [14], which indirectly

indicates the prospects of using nanoparticles obtained by biosynthesis.

For the action of Ni nanoparticles at a concentration of 8 mcg/l, the length of leaves and roots was greater than in the control variant by 41.79% and 36.76%, respectively, however, there was no statistically significant effect of Ni nanoparticles on the energy and dynamics of germination of winter wheat seeds [15], which is consistent with the results of studies on corn seedlings.

Thus, the results obtained are consistent with the results of previous studies and indicate the prospects for using MoS₂ nanoparticles to improve the technology of growing corn.

CONCLUSIONS

It is established that MoS₂ nanoparticles at a lower concentration than 700 mcg/l and all studied concentrations of Zn nanoparticles reduced the length of maize leaf blades by 30.0-60.0% compared to the control variant. The increase in root length is statistically significant only in the MoS₂ 1:10,000 variant. Seed germination during corn processing increased with the use of MoS₂ nanoparticles in subsequent dilutions 1:100, 1:1,000, 1:10,000 by 8.33-13.89%.

Zn and MoS₂ nanoparticles at all the studied concentrations do not significantly affect the germination energy and laboratory germination of seeds. According to the results of statistical processing using the Mann-Whitney test in all the studied variants for the use of Zn and MoS₂ nanoparticles, the changes did not have a sufficient level of statistical significance.

The obtained data from laboratory studies indicate high prospects for the use of MoS₂ nanoparticles in improving the technology of growing corn and the need for further field research on the development of nanofertilisers.

Further research will aim to evaluate other effective concentrations (1: 50,000; 1:100,000) of nanoparticles of MoS₂ and especially Zn (1:20; 1:50), since the effectiveness of using the latter on corn crops has not been proven.

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**Олександр Станіславович Дерев'янку¹, Назанін Магеррамзаде²,
Станіслав Васильович Дерев'янку³**

¹Національний університет біоресурсів та природокористування
03041, вул. Героїв Оборони, 15, м. Київ, Україна

²Національний університет «Чернігівський колегіум» імені Т.Г. Шевченка
14000, вул. Гетьмана Полуботка, 53, м. Чернігів, Україна

³Інститут сільськогосподарської мікробіології та агропромислового виробництва НААН
14000, вул. Шевченка, 97, м. Чернігів, Україна

Оцінка біологічної дії нанокарбоксилатів Zn та наночастинок MoS₂ на проростки кукурудзи (*Zea mays* L.)

Анотація. За необхідності зменшення антропогенного впливу на агроєкосистеми в умовах постійного здороження ресурсів – удосконалення технології вирощування кукурудзи за рахунок застосування нанотехнологій є однією з передумов підвищення урожаю культури та її рентабельності. У зв'язку з цим, метою дослідження було вивчити біологічну активність нанокарбоксилатів Zn та наночастинок MoS₂ за різних концентрацій на проростання, ріст та розвиток проростків кукурудзи. Для визначення впливу наночастинок Zn та MoS₂ проводили дослід на проростках кукурудзи. Схожість та енергію проростання насіння за дії наночастинок визначали відповідно до вимог державного стандарту ДСТУ 4138-2002. Результати дослідження проаналізовані загальноприйнятими статистичними методами. Встановлено, що наночастинок MoS₂ за розведення 1:10000 (у концентрації 700 мкг/л) проявляє біологічну активність та зумовлює збільшення довжини листових пластинок та довжину коренів проростків кукурудзи на 35,0 % та 100,0 % відповідно. За інших концентрацій (1:100; 1:1000) наночастинок Zn та MoS₂ суттєвого впливу на розмір листових пластинок та коренів не спостерігалось. За результатами тесту Мана-Уїтні усі варіанти, за винятком дії наночастинок MoS₂ у розведенні 1:10000 рівень значущості змін був не достатнім. Лише у варіанті MoS₂ 1:10000 зростання довжини коренів було статистично значущим. Не встановлено статистично значущого впливу в усіх досліджуваних варіантах на енергію проростання та лабораторну схожість насіння кукурудзи. Практична цінність наукової роботи полягає у оцінці впливу препаратів (нанокарбоксилатів Zn та наночастинок MoS₂) для позакореневого підживлення, широкий асортимент яких пропонується агровиробникам, підборі ефективних концентрацій на ріст, розвиток і урожайність кукурудзи на зерно

Ключові слова: довжина кореня, довжина листової пластинки, лабораторна схожість, енергія проростання, нанотехнології

Svitlana Kalenska*

National University of Life and Environmental Sciences of Ukraine

03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

Food security and innovative solutions in crop production

Abstract. Global food and energy crises, rational land use, and environmental conservation are urgent problems in the world that determine the existence of human civilisation. The success of solving certain problems requires significant changes and innovative decisions in various production areas and in agriculture in particular. The purpose of the study is to analytically review data on food and energy security, rational use of crop production, problems and innovations in crop production, and identify ways to solve them. When preparing the paper, general scientific research methods were used: analysis and synthesis; system analysis, abstraction and concretisation, interpretation and generalisation of data. Sources for the preparation of the paper were reports of the Food and Agriculture Organisation of the United Nations of the US Department of Agriculture, statistical databases, and scientific sources. The political crisis in the world, population growth, changing consumption patterns, and climate change are driving the level of production and growing demand for crop production. Stabilisation and controlled production, innovations in crop cultivation technologies, land use efficiency, and environmental protection are mutually conditioned and require a comprehensive solution. Global changes in the use of plant material, where in addition to the traditional areas – food, fodder, technical processing – a powerful consumer, bioenergy, has emerged, causing increasing problems. Gas emission, conservation and restoration of plant biodiversity, and ecosystem protection are also pressing issues. Innovative technologies in crop production consider the need to preserve the biodiversity of plants and soil, the efficiency of using CO₂, the latest forms of fertilisers, in particular, nanofertilisers, which provide for targeted, prolonged, regulated use of batteries, minimisation of losses; energy efficiency of technologies, and require constant improvement. These innovative ways of optimising crop production are important for practitioners who can use the proposed solutions in technological processes

Keywords: cereals, oilseeds, bioenergy, rational land use, biodiversity, nanotechnology, CO₂ emission

INTRODUCTION

In modern conditions, with the aggravation of a number of global problems, it is urgent to solve the primary needs of humanity – providing food and energy resources. Crop farming is the basic branch of production, the volume and quality of which can significantly solve the global problems of humanity: providing food, raw materials for industrial processing – the production of biofuels, biomass, and other goods; balanced use and preservation of the environment.

The production of crop products in the world depends on a significant number of factors and the determining factor of gross production is primarily ensuring food security for the growing population of the planet [1-3]. The world's population is projected to grow by 35% by 2050, which may require doubling the yield of agricultural land while eliminating the possibility of expanding agricultural land, in order to preserve natural land, conserve the environment and, in particular, reduce gas emissions [4].

Continued population and consumption growth will mean that global food demand will continue to grow for at least another 40 years [1]. According to the United Nations (UN), about 811 million people, or 9.9% of the world's population, went hungry in 2020; in 2019 – 8.4% of the world's population [2]. In 2020, hunger increased in both absolute and proportional terms, outpacing population growth. More than half of all hungry people – 418 million – live in Asia, more than a third (282 million) in Africa, and 60 million – in Latin America and the Caribbean. The greatest increase in hunger is observed in Africa. According to aggregate data, more than 2.3 billion people, or 30% of the world's population, do not have stable access to sufficient food during the year. This number increased by the same amount in one year as it increased in total over the previous five years [1; 5; 6]. By 2015 and even more, by 2030, a key variable used to

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*Corresponding author

track the development of food security – food consumption per capita will increase significantly. Now there are significant changes in the structure of the use of plant raw materials, which are not limited only to its traditional use for the food industry, feed production, technical processing, but also effectively processed into various types of biofuels [7-9]. The bioenergy sector partially solves energy problems, but exacerbates food problems and requires a balanced solution, considering the use of renewable resources and diversification of energy supply sources, production of lubricants, environmental conservation, conservation and restoration of plant and soil biodiversity [10-12]. Climate change [13; 14], rational use of natural resources and soils [15-17], and growing problems with gas emission [18] are mutually conditioned and their solution is possible through the introduction of innovative technologies into production [19-21].

The purpose of the study is to analyse the state and problems of production and use of basic types of crop products in the world and in Ukraine; identify factors that determine the growth of crop production and innovative solutions in crop production that can significantly affect the stable efficiency of the industry without negative impact on the environment.

STATE, PROSPECTS OF PRODUCTION AND CONSUMPTION OF CROP PRODUCTS

A number of factors cause an aggravation of problems in the world market of crop products [22-24]. The political crisis and rising prices for energy resources cause an increase in prices for resources used in technological processes of crop production, which, in turn, causes an increase in the cost and can lead to a reduction in its production [25-27].

The structure of production and consumption of crop products is determined by the economic, political, social, and cultural characteristics of countries and the planet as a whole [28; 29]. In 2015, the global average

approached 3,000 and will exceed 3,000 kcal/person per day by 2030 [4]. These changes in global averages will primarily reflect an increase in consumption in developing countries, where average consumption will increase from 2,680 kcal in 1997/99; 2,850 kcal in 2015, and about 3,000 kcal in 2030. More and more people will live in countries with medium to high per capita food consumption. For example, by 2015, 81% of the world's population will live in countries with values of this variable exceeding 2,700 kcal/person/day, up from 61% today and 33% in the mid-1970s. Those living in countries where consumption exceeds 3,000 kcal accounted for 48% of the world's population in 2015 and will account for 53% in 2030, up from 42% in 2020 [1].

Grain production

According to the forecast of the Food and Agriculture Organisation of the United Nations (FAO), global grain production in the 2021/2022 marketing year will amount to almost 2,791.3 million tonnes, which will exceed the estimated data for the previous marketing year (MY) by 19.3 million tonnes (0.7%) [1]. Cereals will continue to be the most important source (in terms of calories) of total food intake [24; 30]. Grain consumption continues to grow (Fig. 1). In developing countries, the average consumption of food (grains) per capita in 2000-2010 was 173 kg, which provides 56% of total calories, compared to 141 kg and 61% in the mid-1960s. The level of about 173 kg has been almost constant since the mid-1980s. In developing countries, cereals will continue to provide about 50% of food intake (in terms of kcal/person/day), which is projected to reach almost 3,000 kcal/person/day in 2030 [4]. Wheat consumption will grow per capita, while in developing countries, this growth will be associated with an increase in wheat imports. The increase in demand and trade in coarse grain will be increasingly driven by its use as animal feed in developing countries (Fig. 1).

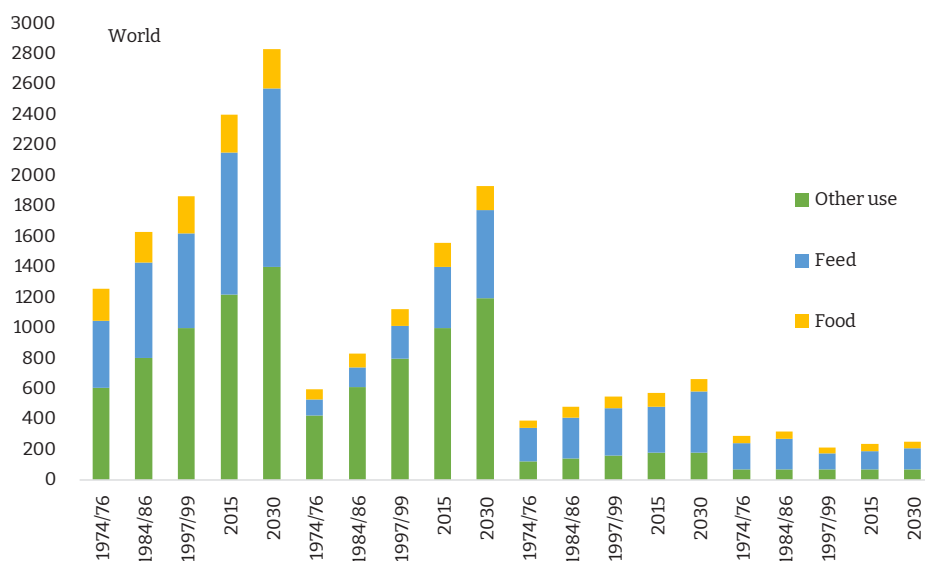


Figure 1. Total consumption of grain crops, by categories of consumption and development of countries, million tonnes

Source: [30]

In 2016-2022, the pattern of grain consumption in these groups of countries remains, with a growing trend in the use of grain for biofuels and feed [26; 30].

Global grain consumption and production are projected to grow by almost a billion tonnes by 2030 from 1.89 billion tonnes in 1997/99 [30]. Of this increase, just over half will be used for feed and about 42% from food, while the remainder will go to other uses (seeds, industrial non-food use, and waste). Feed use will return to the most dynamic element driving the global grain economy, as it accounts for an ever-increasing share of total grain demand.

Developing countries' dependence on grain imports will continue to grow. According to forecasts [30], grain imports by developing countries will increase from 103 million tonnes in 1997/99 (and the projected 110 million tonnes for the current trading year July 2001/June 2002) to 190 million tonnes in 2015 and to 265 million tonnes in 2030 [30]. Traditional grain exporters in the industrial world (USA, Canada, EU, and Australia) are expected to increase their net exports from 144 million tonnes in 1997/99 to 224 million tonnes in 2015, and 286 million tonnes in 2030.

The reasons for the lack of efficiency of the grain industry over the past decades, in addition to purely economic factors, often lie in the structural imperfection of production, commodity resources and consumption of grain, its significant losses in the production process, and the rather high prime cost of grain due to its poor quality [26].

Corn production and consumption in the world is in the first place among grain crops. Global corn production is projected to reach about 1.2 billion tonnes in

2021/2022 [31]. In the 2020/21 marketing year, the largest corn producer in the world was the United States – 384 million tonnes, or a third of global corn production. The largest corn-producing countries in the world in the 2019/20 marketing year were: USA – 31.1%; China – 23.4%; Brazil – 9.07%; EU – 6; Argentina – 4.5%; Ukraine – 3.2%; India – 2.6%; Mexico – 2.25%; South Africa – 1.46%, and other countries – 16.5% [23].

In 2020/21, the United States exported more than 61.5 million tonnes of corn, which is almost a third of the world's total corn exports. The largest consumers of corn in the world in 2020/21 were the following countries: the United States – 12.0 billion bushels; China – 11.3; EU – 3.13; Brazil – 2.77; Mexico – 1.73; India – 1.11; Egypt – 0.67; Japan – 0.63; Vietnam – 0.61; Argentina – 0.59 billion bushels. Total global consumption was 4 45.4 billion bushels [23; 31]

The average price of corn in the world during 2014-2020 ranged from USD 193 per tonne in 2014 to USD 155 per tonne in 2017. However, in 2021, the price increased to USD 250 per tonne, and the trend towards price growth or retention at this level remains [31].

The forecast of the US Department of Agriculture (USDA) [31], made after the beginning of a full-scale war of Russia against Ukraine in February 2022, regarding the production and export of corn for 2022/23 for Ukraine, assumes the lowest gross harvest and export of corn grain after 2010/11, which is associated with a decrease in acreage during a full-scale war (Fig. 2). "Ukraine has become a key exporter of corn over the past decade, but the war is expected to significantly limit these prospects" wrote K. Brown, a global agricultural columnist for the United States [31].

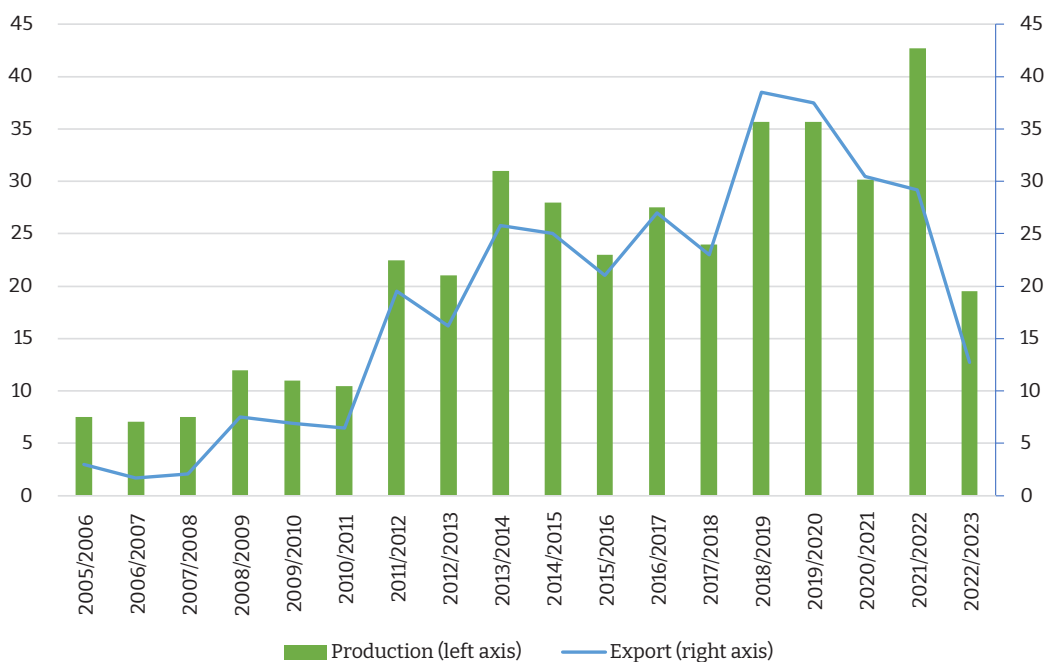


Figure 2. Supply and demand for corn grain in Ukraine, million tonnes

Source: [31]

At the same time, the global corn harvest in the 2022/23 marketing year (MY), according to the USDA, is projected at 180.72 million tonnes, exports – 182.70 million tonnes, final corn reserves in 2022/23 MY in the world will decrease by 4.26 million tonnes – to 305.13 million tonnes [1].

According to the USDA report, the figures in the main exporting countries according to the forecast for 2021/22 MY are estimated at the following level: Argentina: production – 55 million tonnes, exports – 41 million tonnes; Brazil: 126 and 47 million tonnes; Russia: 15.5 and 4.3 million tonnes; South Africa: 17.3 million tonnes, exports – 3.7 million tonnes. Corn production in China will be at the level of 271 million tonnes, which is 1.55 million tonnes less than the forecast for 2021/22 MY (272.55 million tonnes), imports – 18 million tonnes, which is 5 million tonnes less than the forecast for 2021/22 MY (23 million tonnes). Final reserves are projected to decrease by 6.02 million tonnes to 204.22 million tonnes [1; 5; 6].

Production of oilseeds

The growing demand for food in developing countries and the non-food use of oilseeds are the main driving force behind the rapid growth of the oilseeds sector [24; 25; 32] (Fig. 3). Per capita consumption in developing countries

was only 5.3 kg in the mid-1970s; in 1997/99, per capita consumption increased to 9.9 kg [32]. Vegetable oils and petroleum products have relatively high-income elasticity in developing countries, especially in those where the consumption of livestock products and animal fats is likely to remain low due to their high cost and insufficient production in these countries [6; 23]. According to preliminary forecasts for 2010, the consumption per capita of all vegetable oils, oilseeds, and products (expressed in oil equivalent) was expected to increase from 8.2 kg in 1988/90 to 11 kg in 2010 [4; 32]. By 1997/99, it had grown to 9.9 kg. According to current forecasts, demand for food use, per capita for developing countries as a whole, will grow to another 12.6 kg in 2015 and almost 15 kg by 2030. Average food consumption per capita (all food products) in developing countries may increase from 2,680 kcal in 1997/99 to 2,850 kcal in 2015, and to 2,980 kcal by 2030. Approximately 45% of this increase is accounted for by vegetable oils and products with them – this group of products will play an important role in increasing the energy availability of the diet. High growth rates of demand for these calorie-rich foods will lead to excessive average food intake in many countries [2; 3; 32;].

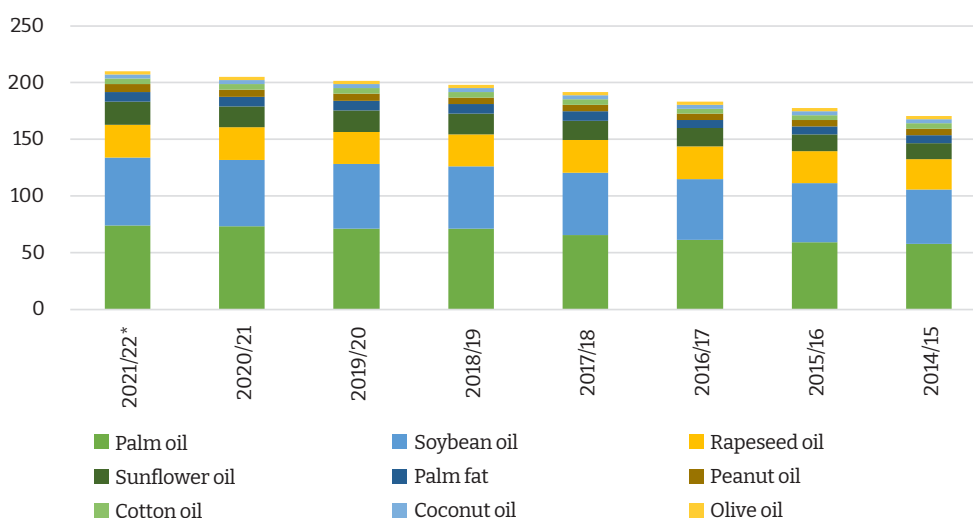


Figure 3. Global oil consumption by type, million tonnes

Source: [32]

Production and demand for rapeseed oil in the world in 2017-2021 slightly decreased in some countries, mainly at the expense of the EU, due to the low rapeseed yield. But the volume of oil production in the main producing countries – Canada, China, and India will rise. Sunflower oil production is projected to increase [23; 32]

Bioenergy and global changes in the structure of plant raw materials use

In addition to the traditional areas of use of crop production – food, feed, technical processing, there is a powerful consumer of plant raw materials – bioenergy, which at the same time caused an aggravation of the problem of

food security in the world [7-9]. Non-food industrial use of oilseeds for the manufacturing of products resulting from such use has a high elasticity of demand in terms of income. It is predicted that the share of total vegetable oil production directed to non-food industrial purposes will continue to grow quite rapidly [24; 25; 32] (Fig. 4). The forecasts consider that this category of demand is growing faster than the growth rate of demand for food – 3.5% per year against 2.1%. The projected rather dynamic growth in demand and the still significant potential for expanding oilseed production in the world and in some of the main exporters indicate that the oilseed market will be actively developing.

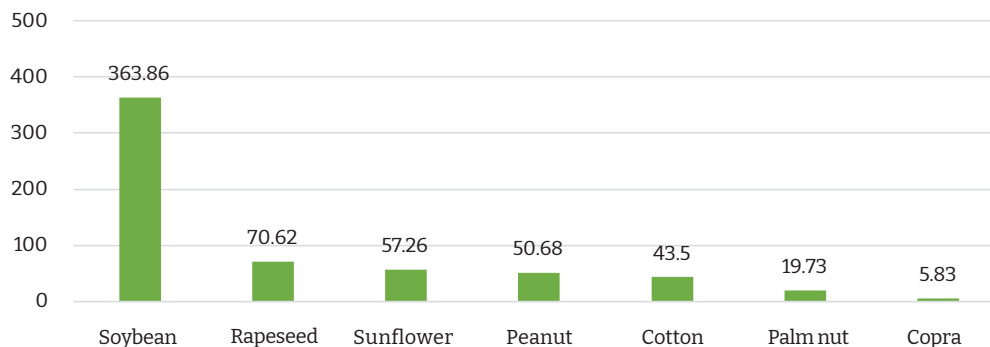


Figure 4. Global production of oilseeds in the world, million tonnes

Source: [32]

Alternative sources of crop raw materials for bio-energy – an urgent need today is conditioned by the need to improve energy efficiency and diversify energy supply sources, produce lubricants, preserve and enrich biodiversity and the environment [11; 33; 34]. Many cultivated plants can be used both for feed and food purposes, and for the production of renewable raw materials [35; 36]. Both areas can compete with each other [8; 11; 25]. Some crops are used only for the production of renewable raw materials [37]. Biomass for energy purposes can be used directly for burning (wood, straw, sapropel (organic bottom sediments)), and in processed form as liquid (rapeseed oil esters, alcohols) or gaseous (biogas – a gas mixture, the main component of which is methane) fuel [34-36]. Industrial, agricultural, and forestry products and household waste decomposed by microorganisms can also be used to produce bioenergy [37].

The raw material of oilseeds has universal use – technical, food, medical, organic fertiliser, and other areas [38-40]. Oils of many crops are suitable for technical use not only in the production of biodiesel, but also in the composition of oils and valuable products [39; 41; 42;].

The use of renewable raw materials for the production of oils and fuels ensures independence from traditional types of energy and lubricants, reducing the negative impact on the environment [10; 43;].

Processing of industrial food production waste from the public consumption network, oils, feed, and others is an area that allows maximising the use of crop products. The waste oil can be used for the production of biodiesel [43]. It is important to assess the energy efficiency of crop biomass production for energy purposes [34; 38].

RESOURCE POTENTIAL AND INNOVATIVE SOLUTIONS IN CROP PRODUCTION

The production of crop products is determined by a significant number of factors, but the key factors are environmental (weather, climate), soil, the plant itself, and the cultivation technology, which should provide optimal conditions for the implementation of the genetic potential of the plant [11; 16]. The uncontrolled increase in crop production, which meets the needs of the world's

population, creates a number of problems, and first of all, it is the problem of preserving the environment: gas emission, loss or inefficient use of plant species, which causes the need to preserve and restore plant biodiversity, protection of natural ecosystems that ensure the preservation of biodiversity [2].

Crop production in the context of global climate change

The world is experiencing global climate change and this will continue due to often unreasonable and uncontrolled human activity aimed at destroying forests and allocating these areas for agricultural land, intensive use of machinery, which can lead to an increase in the concentration of greenhouse gases in the atmosphere for the period from 2010 to 2050 by at least 28% [2; 14]. At the same time, the population is gradually growing, and due to climate change, soil and water resources are being degraded [2; 13]. Many reports of international organisations clearly indicate that the warming of the climate system is unmistakable and most likely caused by natural and human activities [3-5]. Climate change always affects components of the hydrological cycle, such as precipitation, evaporation, temperature, ground water, and finally surface runoff, and can have stronger or weaker, permanent or periodic, beneficial or adverse, harmful, direct or indirect effects on soil processes. Climate change will lead to flooding and drought, which will have a multi-vector impact on soil, water availability, and vegetation. Temperature and water are very important factors that affect the growth and development of plants and in conditions of fairly dynamic climate changes should have a fairly high adaptation potential [44; 45]

Significant technological advances and innovations have been made to address the growing challenges of sustainable production and food security [20; 46; 47]. The growing demand for food products in the world causes an increase in the intensity of crop production, which leads to chain negative consequences – soil depletion, reduced crop yields, and a significant increase in economic and energy costs [48]. About 40% of the world's agricultural land has been degraded due to intensive production, which has led to significant losses in soil

fertility [49]. Sustainable agriculture involves reducing the use of agrochemicals, which has a positive impact on the environment, preserving species from extinction, improving management and conservation tactics by reducing the cost of agricultural resources [50; 51].

Currently, a significant amount of research is being conducted, analysing the factors that most determine the level of crop production. Climate changes and the yield potential that can be obtained under these variable conditions are analysed. Various methods of calculating and modelling processes are used. J. Wart *et al.* analysed and developed a protocol to eliminate the gap between the yield potential (Yp – yield obtained without stress factors: no pests, diseases, nutrient supply, water stress) and the current average yield [52]. Quantifying the yield gap is important for informing policy makers and prioritising research to achieve food security without compromising the environment. The study was based on examples of irrigated rice in China, irrigated and rainfed corn in the United States, and rainfed wheat in Germany. Sensitivity analysis of the simulated Yp and Yw showed that reliable estimates require specific information on crop management, +15 years of observation of daily climate data from weather stations in major crop production areas, and coverage of 40-50% of the total national production sector. National Yp estimates were weighted according to potential production within 100 km of reference weather stations. This protocol is suitable for countries that mainly grow crops in landscapes with relatively uniform topography, such as prairies, plains, large valleys, deltas, and lowlands, which account for the majority of global food crop production. The results are consistent with the hypothesis by M. Waldrop & M. Firestone that the average farm “reaches” plateaus when they reach 75-85% of the estimated national yield potential [51]. This is possible for rice in China and wheat in Germany.

Land resources play a particularly important role in human life and production activities, their rational use and conservation, and increasing soil fertility are essential conditions for building up the food potential of countries. According to the FAO [2; 6; 25], it is now about 11% (1.5 billion hectares) of the total surface of our planet (13.4 billion hectares) is used in crop production (arable land and the area under perennial crops). This area is just over a third (36%) of the land area, which is estimated to be somewhat suitable for crop production. The fact that about 2.7 billion hectares with potential suitability for crop production remain indicates that there is still room for further expansion of agricultural land. However, there are also opinions that there are no more areas for cultivation or there are very few of them. It is believed that an increase in crop production should occur without expanding arable land. However, it is calculated that if humanity does not intervene, then according to forecasts, by 2050 agricultural land may expand by 600 million hectares, which would lead to further irreversible climate changes [2]. Thus, the growth of gross crop production

should occur at the expense of innovative technological projects.

Approaching the “net-zero CO₂ emissions” goal is the way to stop climate change

Agriculture has never been the focus of sources of gas emissions other than soil carbon fixation. However, now there is a growing share of agriculture in gas emissions and in order to limit agriculture to a “fair” share for an increase in air temperature by 2°C it is necessary to increase food production by 50% while reducing emissions by 2/3 compared to 2010. In order to remain at the level of 1.5°C rising temperatures, these emissions should be further reduced by the reforestation of 585 million hectares due to a decrease in agricultural land with a simultaneous increase in production and increasing demand for food [2]. Since the use of crop raw materials has a zero balance of carbon dioxide, since it is assimilated by the plant to form organic matter, which has a multi-vector use – the expansion of crop production using adaptive technologies will contribute to an approach to “zero CO₂ emission” [18].

AREAS OF INNOVATIVE SOLUTIONS IN CROP PRODUCTION

Soil fertility and biodiversity of soil microflora

One of the innovative solutions that can contribute to the optimal supply of plants with the necessary nutrients and soil acidity is to preserve the biodiversity of soil microflora. The intensification of crop cultivation technologies significantly affects the conservation of soil microflora biodiversity. The efficiency of using mineral and organic fertilisers is relevant [53]. Elevated nitrogen fertiliser rates affect microbial activity by altering microbial biomass [54]. There is a dynamic change in the bacterial [17; 55] and fungal communities [56; 57], followed by a change in their ecological function. The biodiversity of soil microbial communities depends both on the introduction of mineral nitrogen and is largely determined by crop rotations [58], precipitation [59], temperature [15], and seasonal changes [60].

The combined use of inoculation of seeds by bacterial strains and regulation of nitrogen fertiliser norms in crop cultivation technologies indicates their different effectiveness depending on a number of factors [61-63].

Innovative improvement of plants

The achievement of selection – “improvement” of plants, in the mid-20th century contributed to a significant increase in crop yields. “Improvement” of plants – selection, genetics, and biotechnology contribute to the establishment of the genetic potential of plants with high yield, product quality, adaptive properties, stability, and plasticity [11; 45]. Each of the “Green Revolutions” caused by the development of science provides a doubling of yields. The first “Green Revolution”, which began in the middle of the 18th century, is associated with the discovery

of the role of legumes in enriching the soil with nitrogen due to symbiotic nitrogen fixation. The second “Green Revolution” in the middle of the 19th century is the result of the invention of the theory of mineral nutrition and the widespread use of fertilisers. The third “Green Revolution” took place in the 1950s and 1960s and is associated with significant achievements in the field of genetics, selection, new agrobiotechnologies, and plant protection. Using selection, plants are created that develop faster, absorb solar radiation more efficiently, and synthesise dry matter more intensively. Due to this “Green Revolution”, it was possible to significantly increase the yield – by 20-70%, depending on the crop [11]. The development of short-stemmed wheat and rice varieties that can respond positively to fertilisers without lodging crops has provided a significant part of the world’s population, especially in developing countries, with grain [45]. Wheat grain production, due to advances in farming and cultivation technologies, increased from 222 to 779 million tonnes in the period 1961-2021, and rice – from 216 to 517 million tonnes [5; 6]. In developing countries, one person consumes about 173 kg of grain per year [4]. Thus, the achieved growth in grain production provides an additional 5 billion people with grain every year.

Now there is a challenge for the next “Green Revolution” or “Underground Revolution” – a change in the architectonics of the root system, which is based on increasing the yield of crops for growing on low-fertile soils by farmers who are unable to purchase fertilisers, which is the majority of farmers in the third world [64]. Just as the previous “Green Revolution” was based on crops, varieties that responded positively to high soil fertility, the fourth “Green Revolution” will be based on crops that are tolerant to low-fertility soils. Jonathan Lynch points out that “...strategies of the past do not work now to meet the growing nutritional needs” [64]. Roots are the key to the “Green Revolution”, a key that does not require expensive additional costs. The roots provide moisture and nutrients – often two limiting factors that the plant needs. The roots are more effective when adapted to the environment [65].

Identification and selection of plant species with different types of photosynthesis is one of the main and least expensive ways to increase crop production and provide the population with food [66-68]. The efficiency of nitrogen uptake by plants is closely related to the type of photosynthesis of plants and the supply of moisture [69]. An extremely important area is the development of crop models that use photosynthetically active radiation with maximum efficiency, which leads to an increase in technological, economic, and energy efficiency [70; 71].

Stability and plasticity of plants of varieties and hybrids of agricultural crops

The combination of ecological stability of the crop, variety, hybrid, and cultivation technology, considering the yield and quality of crop production, economic and energy

efficiency is not only important, but also a complex task of selection and meeting the genetic potential through adaptive cultivation technologies [65; 52]. The growth of crop productivity actually depends on the genotype – its ability to interact with environmental conditions, cultivation technology, the implementation of potential at a high level under specific growing conditions and high resistance to stress factors [44].

Seed quality, promotion of seed germination, prevention of seed injury – the basic basis of crop cultivation technologies [72-74]. The economic activity of seeds is a determining factor that regulates the terms and conditions of seed storage.

Innovative solutions in plant nutrition

The need for growth in crop production determines the search for balanced ways to solve them, and, in particular, it is the combined provision of plants with nutrients through the use of various forms of mineral fertilisers, organic fertilisers, biologics with specific microorganisms, etc. [75]. Currently, the global ecosystem receives elevated nitrogen levels, which on average already exceed 100 kg N/ha [76; 77]. It is estimated that the global rate of nitrogen application in terrestrial ecosystems is likely to increase by 2.5 times over the course of a century [78]. Studies show that increased nitrogen content in ecosystems leads to climate change, greenhouse gas emissions, species extinction, and even a threat to human health [79]. The latest forms of fertilisers, the use of which provides for the targeted use of nutrients: prolonged action of fertilisers [80; 81], can increase the targeted use of nutrients, reduce the application rates, and negative impact on the environment.

Nanotechnologies in crop production marked the beginning of a new technological revolution for the cultivation of agricultural crops and became key technologies of the 21st century [20; 22; 50]. Nanotechnologies have many promising areas of use in crop production: a source of nutrients, activation, and growth of photosynthesis productivity, immunocorrectors, antistressors, nanopesticides, specific root effectors for rooting shoots and tissue crops, drugs of multivalent action to increase plant resistance to stress [82-84]. An important role is assigned to nanofertilisers and growth-stimulating complexes [47; 50; 85;]. The efficiency of using nutrients from conventional fertilisers does not exceed 30-40% [86] and largely depends on the final concentration of fertilisers reaching the target site. Repeated use of excessive amounts of conventional fertilisers negatively affects the inherent balance of soil nutrients, the purity of the aquatic environment, drinking water pollution, and the development of flora and fauna [87; 88].

Nanofertilisers synthesised specifically for the regulated release of nutrients depending on the needs of crops, minimising differential losses, have a huge potential [86; 89; 90]. Controlled release of nanoparticles improves plant growth and development, increases yield,

and improves product quality [49; 91; 92;]. The approach to targeted delivery of batteries based on nanoscale particles is used to optimise the production process, directionally changing its passage, by certain areas of their functional efficiency [86; 93; 94;].

Fertiliser nanoformulas synchronise the “release” of nanoparticles with the need for culture, which prevents the loss of nutrients by direct use by plants, avoiding the interaction of nutrients with soil, water, air, and microorganisms [51; 95].

Energy efficiency of crop production

The use of energy in agricultural production is growing 40-80% faster than in many other sectors of the world economy, the technological process in which is more sustainable in terms of expanding the use of additional resources [1; 3; 25] due to the high energy consumption in the process of crop production, in particular, the use of mineral fertilisers, pesticides, complex machinery, fuel and other things, the question arises whether agricultural production is still energy efficient. It is established that each of the “Green Revolutions”, the latest technologies for growing agricultural crops require an increase in energy consumption and resources per unit of production and leads to an increasing impact on the environment [27; 29; 30].

S. Bielski *et al.* investigating the energy efficiency of growing triticale for the purpose of using grain for the production of bioethanol, showed that the energy value of the produced bioethanol in technologies with high energy consumption was lower than the energy costs for the production of raw materials and their processing [7]. At the same time, studies using different levels of mineral nutrition showed that the processing of winter triticale

grain for bioethanol achieved the most favourable value for the production system with low energy consumption [7] the most energy-intensive operation in triticale cultivation technology, according to the results of the study was mineral nutrition. The high-consumption cultivation technology had significantly lower energy efficiency than other technologies.

CONCLUSIONS

The growing population of the planet, political crises, competition for natural resources and energy, causes an aggravation of a number of global problems: food and energy security, environmental protection. This analysis proves that humanity is able to solve these problems and not go beyond the irreversible line between human needs and the preservation of the planet.

Conservation of plant biodiversity, efficient use of photosynthetically active radiation, expansion of cultivation of crops with different types of photosynthesis, and innovations in cultivation technologies are the basis for crop production to ensure food security and raw materials for industrial processing.

Innovative solutions in crop cultivation technologies are the use of nanofertilisers, which have a number of advantages over conventional ones – low application volumes, targeted use of nutrients, and the possibility of using them during a long growing season. At the same time, questions about nanoelements and the environment are still poorly understood.

Innovative varieties and hybrids of crops created according to the optimal plant morphotype are able to effectively use environmental and technological factors of the environment and form the yield and quality of products with significantly lower economic and energy costs.

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Світлана Михайлівна Каленська

Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна

Продовольча безпека та інноваційні рішення в рослинництві

Анотація. Глобальна продовольча та енергетична кризи, раціональне землекористування та збереження довкілля є актуальними проблемами в світі, які обумовлюють існування людської цивілізації. Успіх вирішення визначених проблем потребує суттєвих змін та прийняття інноваційних рішень у різноманітних виробничих сферах та в сільському господарстві зокрема. Метою дослідження є аналітичний огляд даних щодо продовольчої та енергетичної безпеки, виробництва та раціонального використання продукції рослинництва, проблем та інновацій в рослинництві, визначення шляхів їхнього вирішення. При підготовці статті використанні загальнонаукові методи дослідження: аналіз і синтез; системний аналіз, абстрагування і конкретизація, інтерпретація та узагальнення даних. Джерелами за підготовки статті були звіти Продовольчої і сільськогосподарської організації об'єднаних націй Міністерства сільського господарства США, статистичні бази даних та наукові джерела. Політична криза в світі, зростання чисельності населення, зміна структури споживання, зміна клімату обумовлюють рівень виробництва та зростаючий попит на продукцію рослинництва. Стабілізація та контрольоване виробництво, інновації в технологіях вирощування культур, ефективність використання земельних угідь, захист довкілля є взаємообумовленими і потребують комплексного вирішення. Глобальні зміни в структурі використання рослинної сировини, де окрім традиційних напрямів – продовольство, корми, технічна переробка, з'явився потужний споживач – біоенергетика, обумовлюють загострення проблем. Емісія газів, збереження та відновлення біорізноманіття рослин, захист екосистем також є нагальними проблемами. Інноваційні технології в рослинництві, враховують необхідність збереження біорізноманіття рослин та ґрунту, ефективність використання CO₂, новітніх форм добрив, зокрема нанодобрив, які передбачають цільове, пролонговане, регульоване використання елементів живлення, мінімізації втрат; енергетичну ефективність технологій та потребують постійного удосконалення. Наведені інноваційні шляхи оптимізації виробництва в рослинництві є важливими для практиків, які можуть використовувати запропоновані рішення в технологічних процесах

Ключові слова: зернові культури, олійні культури, біоенергетика, раціональне землекористування, біорізноманіття, нанотехнології, емісія CO₂

Semen Tanchyk*, Oleksandr Pavlov, Antonina Babenko

National University of Life and Environmental Sciences of Ukraine

03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

Control of weeds in spring barley crops at different times of herbicide application

Abstract. Weeds can significantly reduce the yield of spring barley, so research is relevant to determine the optimal time for applying herbicides based on modern active substances to control a wide range of weeds. In this regard, the purpose of this study is to determine the effectiveness of the Kvelex preparation based on new active substances halauxifen-methyl and florasulam in comparison with Lancelot 450 WG against annual and perennial dicotyledonous weeds during introduction into various phases of crop development and weeds in spring barley crops. The leading approaches to solving this problem are conducting field studies to determine the biological effectiveness of herbicide variants and statistical methods (dispersion, correlation) to determine the accuracy and reliability of experimental data. As a result of the conducted studies, it was found out that in the case of contamination with annual weeds *Cenopodium album* L., *Polygonum convolvulus* L., *Amaranthus retroflexus* L., herbicide application is best carried out in the cotyledon phase – the first pair of real weed leaves, which corresponds to the BBCH 18 phase of spring barley. This provided the highest efficiency against these species at 95.5% for Kvelex and 94.4% – Lancelot, 450 WG. But at this stage, the effectiveness against *Cirsium arvense* (L.) and *Scop. Sonchus arvensis* L. is up to 94% and 86.6%, respectively. However, thistles are significantly suppressed and do not compete for the crop in the future, which facilitated a significantly higher yield of spring barley (4.5 t/ha for applying Kvelex and 4.42 t/ha for using Lancelot 450 WG) compared to options where herbicides were applied in the BBCH 25-30 phases of the crop. The materials of the study are of practical value for farmers in choosing the phase of development of weeds and crops when applying herbicides in spring barley crops

Keywords: Kvelex, Lancelot 450 WG, biological efficiency, yield

INTRODUCTION

Spring barley is one of the most common grain crops in Ukraine. Its area is stable in the range of 1.34-1.63 million hectares. Weeds are a significant factor in limiting the yield of this crop. According to the study by L. Pelekh, the most negative impact on the yield of spring barley begins from 30 days after germination of the crop. The presence of weeds in the range from 75 to 112 units/m² reduces crop yield by 49-62.4% [1].

The decrease in the yield of grain crops largely depends on the species diversity of weeds, the level of their presence, the situation with the soil and the environment, and the accepted methods of weed control [2; 3]. In addition to direct influence on the cultivated plant (reduced yield), weeds can also have an indirect effect, in particular, perform the function of a “reservoir” of mycotoxicogenic

fungi, which are producers of mycotoxins that accumulate in the crop [4]. The most common and problematic weed species in the agrocenosis of spring barley in Ukrainian and European fields are yellow foxtail (*Setaria glauca* (L.) Beauv.), cockspur (*Echinochloa crus-galli* (L.) Beauv.), charlock mustard (*Sinapis arvensis* L.), red-root amaranth (*Amaranthus retroflexus* L.), white goosefoot (*Chenopodium album* L.), pale persicaria (*Polygonum lapathifolium* L.), wild buckwheat (*Polygonum convolvulus* L.), common ragweed (*Ambrosia artemisiifolia* L.), white campion (*Melandrium album* (Mill.) Garcke), field pennycress (*Thlaspi arvense* L.), creeping thistle (*Cirsium arvense* (L.) Scop.), sow thistle (*Sonchus arvensis* L.), field bindweed (*Convolvulus arvensis* L.) [5-7].

Despite sufficiently investigated weed control measures, numerous herbicide-resistant weed genotypes are

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*Corresponding author

rapidly evolving in agricultural crops and chemical control capabilities are decreasing in many production systems [8; 9]. For example, Larran *et al.* [10] in their study indicate the distribution of populations of *Amarantus palmeri* resistant to herbicides of the glyphosate group and acetolactate synthase (ALS) inhibitors. Therefore, it is necessary to develop and test new active ingredients with different mechanisms of action on weeds to avoid resistance.

It is important to apply herbicides in time, as their use in later phases leads to poorer weed control and, as a result, to lower crop yields. In the studies of Polish researchers, the smallest increase in the yield of spring barley was conditioned by the introduction of herbicides in the BBCH 31 development phase compared to BBCH 25-26 [11]. The most harmful to spring barley are perennial species, in particular, *Cirsium arvense* (L.) Scop. and *Sonchus arvensis* L., *Convolvulus arvensis* L., *Elymus repens* L. To eliminate these weeds, it is important to select the phase when they are most sensitive to herbicides. In particular, Tavaziva *et al.* [12] indicate that growth and development of *C. Arvense* were most effectively suppressed when herbicide spraying was carried out during the development of four leaves on the largest shoot, which corresponds to 13 cm, and

not 15-20, as recommended in the literature. To date, 498 biotypes of weeds that are resistant to various herbicides, including active substances from the groups of sulphurea, imidazolinones, and azoles have been identified [13; 14].

The purpose of this study is to investigate the effectiveness of Kvelex based on new active substances halauxifen-methyl and florasulam in comparison with Lancelot 450 WG in spring barley crops. The goal of the study is to determine the biological effectiveness of herbicides against dicotyledonous annual (catchweed, black nightshade, pale persicaria, wild buckwheat, white goosefoot, red-root amaranth, etc.) and perennial (creeping thistle and sow thistle) weeds for introduction into different phases of crop and weeds development.

MATERIALS AND METHODS

Studies to determine the effectiveness of herbicides against dicotyledonous annual and perennial weeds in spring barley crops were conducted for 3 years (2020-2022). For this purpose, a field small-scale experiment was conducted on the premises of the special subdivision "Agronomic Experimental Station" of NULES of Ukraine according to the following scheme (Table 1).

Table 1. Experiment scheme

No.	Variants	Drug consumption rates l/ha, kg/ha	BBCH culture development phase
1	Kvelex + Vivolt	0.05 + 0.4	15-20
2	Lancelot 450 WG + Vivolt	0.033 + 0.4	
3	Kvelex + Vivolt	0.05 + 0.4	22-28
4	Lancelot 450 WG + Vivolt	0.033 + 0.4	
5	Kvelex + Vivolt	0.05 + 0.4	30-32
6	Lancelot 450 WG + Vivolt	0.033 + 0.4	
7	Control	–	

Note: Kvelex – halauxifen-methyl 100 g/kg + florasulam 100 g/kg + cloquintose-acids 70.8 g/kg (antidote); Lancelot 450 WG – florasulam 150 g/kg + aminopyralide 300 g/kg; Vivolt – ethoxylate + isodecyl alcohol (alpha-isodecyl-omega-hydroxypoly-oxyethylene). The working fluid consumption rate is 200 l/ha

The experiment is based on 4-fold repetition. Experiment area – 560 m². The area for each variant is 80 m². The placement of repetitions and variants in the experiment is randomised. The test preparations were applied with a Jacto pjb-16C satchel sprayer.

In the experiment, spring barley of the Sebastian variety was sown, the seeding rate was 4 million germinated seeds/ha, seeding depth – 3-4 cm, row spacing – 15 cm, predecessor – sunflower. Protection of the crop from diseases and pests is the same for all variants and included seed treatment before sowing with a mixture of Gaucho Evo 275 FS TN (clothianidine, 100 g/l + imidacloprid, 175 g/l) at a rate of 1.0 l/t and Lamardor Pro 180 FS TN (protioconazole, 100 g/l + tebuconazole, 60 g/l + fluopyram, 20 g/l) at a rate of 0.5 l/t. Post-germination protection included a single application of the Falcon fungicide (tebuconazole,

167 g/l + triadimenol, 43 g/l + spiroxamine, 250 g/l) at a rate of 0.6 l/ha and Decis f-Lux insecticide (deltamethrin, 25 g/l) at a rate of 0.4 l/ha. The soil of the experimental plots is represented by typical medium-loamy chernozem.

To calculate the biological effectiveness of the studied herbicides, the equation was used [15; 16]:

$$E = \frac{100 \cdot (A - B)}{A} \quad (1)$$

where: E – biological efficiency of the herbicide, %; A – number of weeds in the control variant, units/m²; B – number of weeds in the experimental variant, units/m²;

Records of the number of weeds and the biological effectiveness of herbicides were carried out on Day 14, Day after each treatment and before harvesting separately for each type of weed.

Since the studied preparations were introduced into different phases of crop development, the number of weeds and the phase of their development before the introduction of herbicides significantly differed. The introduction of herbicides in the first term occurred in the BBCH 18 development phase of spring barley. The species saturation was up to 10 species per 1 m². All areas where the study was conducted had a strong level of contamination – from 77.8 to 90.5 units/m². The following crops were dominant: white goosefoot (*Chenopodium album* L.), wild buckwheat (*Polygonum convolvulus* L.), red-root amaranth (*Amaranthus retroflexus* L.); subdominant species were: catchweed (*Galium aparine* L.), pale persicaria (*Persicaria lapathifolia* L.), creeping thistle (*Cirsium arvense* (L.) Scop.); related species: chickweed (*Stellaria media* (L.) Vill.), black nightshade (*Solanum nigrum*), white campion (*Melandrium album* Mill.), sow

thistle (*Sonchus arvensis* L.). Phases of development of dicotyledonous annual weeds – cotyledons – the appearance of the first pair of real leaves; dicotyledonous perennials – the rosette phase. Second-term drugs were introduced into the BBCH 25 development phase of the crop. The same types of weeds were present in the crops in the same proportions. The development phase of thistles was 8-10 leaves, other dicotyledonous weeds – from 4 to 6-8 leaves, depending on the species. The development phase of spring barley in the third period of herbicide application was BBCH 30. The species composition of weeds has not changed. The development phase of thistles was 10-12 leaves, dicotyledonous annual weeds – from 4 to 6-10 leaves, depending on the species. Figure 1 shows the species composition and average number of weeds present in spring barley crops at the time of application of the herbicides under study.

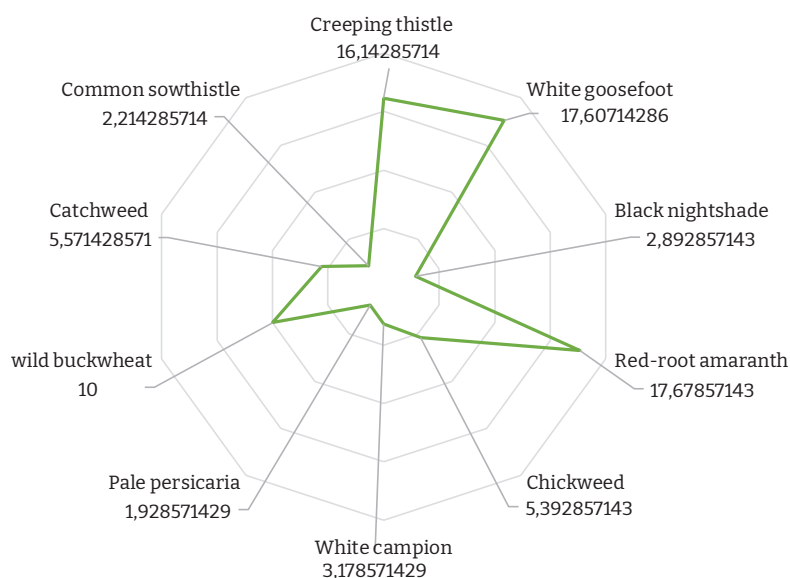


Figure 1. Species composition and number of weeds at the time of herbicide application

The yield of spring barley was determined in the phase of full ripeness of the crop by continuous harvesting from each site separately, bringing it to 100% purity and standard humidity.

Statistical analysis of the obtained data was performed using MS Office 365 Excel and Statistica 10 software suites.

RESULTS AND DISCUSSION

The first quantitative accounting of contamination of spring barley crops was carried out on Day 14 after the introduction of preparations. Their effect, depending on the time of application and the variant, had different degrees of severity. There was a significant decrease in the number of vegetative weeds and inhibition of the growth and development of not yet dead specimens. In the control

variant, the increase in the number of weeds was 14.9% compared to the initial value. The number of weeds in the experimental variants was 22.3-32.3 units m² depending on the option. All variants had significant differences with the control. Further records noted a decrease in the number of weeds in crops with herbicidal variants. The lowest number of annual weeds 56 days after herbicide application was recorded for the use of drugs in the BBCH 18 phase of the crop, when the weeds were in the phase of cotyledon-first pair of real leaves. In this case, their number was 4.5 units/m² for Kvelex and 4.8 units m² for Lancelot 450 WG. When herbicides were applied in the later phases of crop development, the number of weeds was higher and amounted, respectively, to 7.8 and 10.3 units/m² for spraying in the BBCH 25 phase and 13.0 and 14.3 units/m² – BBCH 30 (Fig. 2).

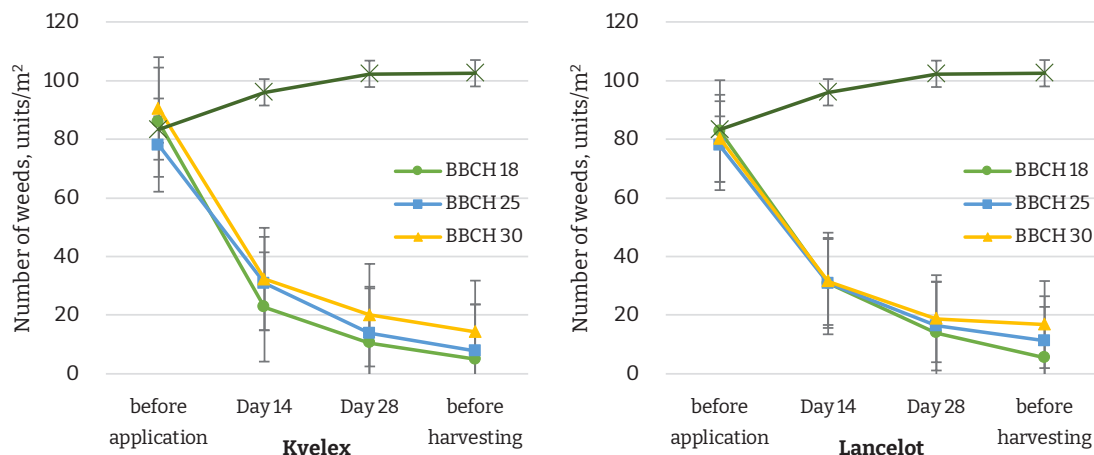


Figure 2. Dynamics of the number of weeds depending on the period of application of herbicides, units/m²

The biological effectiveness of the drugs in % was calculated for each type of weed. On Day 14 after applying herbicides, their overall biological effectiveness was in the range of 65.5-79.9% in the absence of a significant difference between the variants. However, the analysis for each type of weed separately showed significant differences between the variants depending on the application phase and the active substance of the drug. Significantly higher efficiency against perennial dicotyledonous rod-root

weeds *Cirsium arvense* (L.) and *Sonchus arvensis* L. was noted when applying herbicides to later phases. When applying Kvelex and Lancelot 450 WG in the development phase of spring barley BBCH 25, their effectiveness against these weeds was 92.7 and 91.0%, respectively, and BBCH 25 – 95.8 and 90.0%, while the use of these drugs in the earlier stages of BBCH 18 in crops and the rosette phase in thistles provided significantly lower efficiency at the level of 76.1-69.7% (Table 2).

Table 2. Biological effectiveness of herbicides depending on the application period, %

Variant	Accounting period	Types of weeds										Total
		<i>Cirsium arvense</i> (L.) Scop.	<i>Chenopodium album</i> L.	<i>Solanum nigrum</i>	<i>Amaranthus retroflexus</i> L.	<i>Stellaria media</i> (L.) Vill.	<i>Melandrium album</i> Mill.	<i>Persicaria lapathifolia</i> L.	<i>Polygonum convolvulus</i> L.	<i>Galium aparine</i> L.	<i>Sonchus arvensis</i> L.	
BBCH 18												
1	Day 14	76.1	76.6	93.8	72.2	88.2	77.5	82.5	68.6	90.0	73.3	79.9
	Day 28	86.2	95.1	95.8	88.6	94.5	77.5	86.3	79.7	89.7	73.3	86.7
	before harvesting	90.4	95.9	100.0	94.9	100.0	100.0	98.8	95.6	100.0	81.7	95.7
2	Day 14	69.7	70.8	66.7	67.5	80.6	62.5	68.8	62.6	63.4	44.2	65.7
	Day 28	83.2	82.6	100.0	85.0	100.0	87.5	68.8	83.1	94.0	72.9	85.7
	before harvesting	86.0	91.0	100.0	97.3	100.0	100.0	81.3	95.0	100.0	75.0	92.5
BBCH 25												
3	Day 14	92.7	42.6	51.8	53.7	80.5	75.0	75.0	58.8	65.6	100.0	69.6
	Day 28	96.2	74.7	87.9	76.3	97.5	87.5	75.0	82.5	81.5	100.0	85.9
	before harvesting	100.0	78.6	83.9	88.4	100.0	100.0	100.0	87.5	96.4	100.0	93.5
4	Day 14	91.0	44.6	73.3	51.9	79.6	41.7	84.4	52.1	64.4	91.7	67.5
	Day 28	92.7	74.1	78.3	77.6	93.1	80.2	90.6	82.0	75.6	100.0	84.4
	before harvesting	97.3	76.9	77.8	81.7	96.3	96.9	90.6	86.7	96.9	100.0	90.1

Table 2, Continued

Variant	Accounting period	Types of weeds										Total
		<i>Cirsium arvense</i> (L.) Scop.	<i>Chenopodium album</i> L.	<i>Solanum nigrum</i>	<i>Amaranthus retroflexus</i> L.	<i>Stellaria media</i> (L.) Vill.	<i>Melandrium album</i> Mill.	<i>Persicaria lapathifolia</i> L.	<i>Polygonum convolvulus</i> L.	<i>Galium aparine</i> L.	<i>Sonchus arvensis</i> L.	
BBCH 30												
5	Day 14	95.8	42.9	52.5	54.1	85.2	50.0	93.8	60.4	60.6	100.0	69.5
	Day 28	96.7	67.9	78.3	68.0	91.4	81.3	100.0	73.0	77.0	100.0	83.4
	before harvesting	99.2	76.0	74.2	77.4	91.4	75.0	77.1	82.2	96.9	100.0	84.9
6	Day 14	90.0	42.6	57.5	47.1	78.8	60.8	71.9	57.5	61.4	87.5	65.5
	Day 28	93.9	71.0	58.4	61.3	96.9	80.4	96.9	80.2	68.1	90.0	83.0
	before harvesting	96.3	65.2	66.8	61.3	96.9	76.8	62.5	82.4	96.4	100.0	80.5
LSD ₀₅	Day 14	9.6	12.5	F _f <F ₀₅	14.5	F _f <F ₀₅					28.1	F _f <F ₀₅
	Day 28	7.2	15.4	F _f <F ₀₅	12.6	F _f <F ₀₅	33.1	F _f <F ₀₅			26.4	F _f <F ₀₅
	before harvesting	5.5	15.9	F_f<F₀₅	9.6	F_f<F₀₅					17.9	7.1

However, better control of annual weeds such as *Chenopodium album* L. and *Amaranthus retroflexus* L. was made by the preparations in the phase cotyledon-first pair of true leaves in weeds, which falls on the BBCH 18 phase in spring barley. In particular, against *Chenopodium album* L. the effectiveness of Kvelex introduced in the first term was 76.6%, against *Amaranthus retroflexus* L. – 72.2%, which is at the level of Lancelot 450 WG with indicators, respectively, 70.8% and 67.5%.

The analysis of variance did not reveal significant differences in the biological effectiveness of the studied herbicides against *Stellaria media* (L.) Vill., *Melandrium album* Mill., *Persicaria lapathifolia* L., *Polygonum convolvulus* L. and *Galium aparine* L. However, it was also generally higher for the introduction of herbicides in the early stages of weed development. Notably, the weeds that were not destroyed were in a depressed state and lost their competitiveness to cultivated plants.

Records conducted on Day 28 generally showed an increase in the biological effectiveness of herbicides on all the studied variants to 83.0–86.7%, but no significant difference was found between them. Analysis for each type of weed separately confirmed previous trends in the effectiveness of drugs. Thus, the highest effectiveness of Kvelex against thistles *Cirsium arvense* (L.) and *Sonchus arvensis* L. was achieved by applying it in BBCH phases 8–12 of weed leaves and was 96.2–100.0%, and annual weeds – in the early stages of their development and was 77.5–95.8%.

At the time of the last accounting before harvesting spring barley, the number of weeds in the experimental plots decreased compared to the previous accounting. The surviving weeds were in neotenic form and were not able to significantly replenish the seed

bank of the soil and cause damage to the crop, although some of them formed seeds.

As a result, the biological efficiency of herbicides introduced in the first term was the highest in the experiment and amounted to 95.7% for Kvelex and 92.5% – Lancelot 450 WG. The introduction of these drugs in the second term reduced their overall effectiveness, respectively, to 93.5% and 90.1%, but this decrease was not significant. The use of drugs in the third term significantly reduced their effectiveness to 84.9% and 80.5%. The high control of *Stellaria media* (L.) Vill., *Melandrium album* Mill., *Persicaria lapathifolia* L., *Polygonum convolvulus* L., *Galium aparine* L. was shown by all the options, regardless of the time of application of drugs. However, in general, the introduction of herbicides in the early stages of development of these weeds provided higher biological efficiency and faster death. In fields that are significantly clogged with perennial root-and-shoot weeds (*Cirsium arvense* (L.) and *Sonchus arvensis* L.) it is more appropriate to use these drugs in the second term (BBCH 25 of spring barley and 8–10 leaves of thistle), which would provide almost 100% destruction of perennial weeds and quite effectively control annual species.

The yield of spring barley in the control version was 2.24 t/ha. The introduction of the studied drugs significantly increased the yield of the crop. The introduction of Kvelex and Lancelot 450 WG in the BBCH 18 phase of spring barley provided the highest yield increase, respectively, 101.1% and 97.7%. The use of these drugs in later phases of crop and weed development provided a smaller increase in crop yield: BBCH 25 – 94.3% and 89.3%; BBCH 30 – 86.8% and 85.8%. There was a close inverse correlation ($r = -0.99$) between crop yield and weed abundance, and a close direct correlation between herbicide yield and

biological efficiency ($r = 0.9$). Thus, the use of herbicides at a later stage of crop development (BBCH 25-30) led to

a significant decrease in the yield of spring barley compared to their use in the early stages (BBCH 18) (Fig. 3).

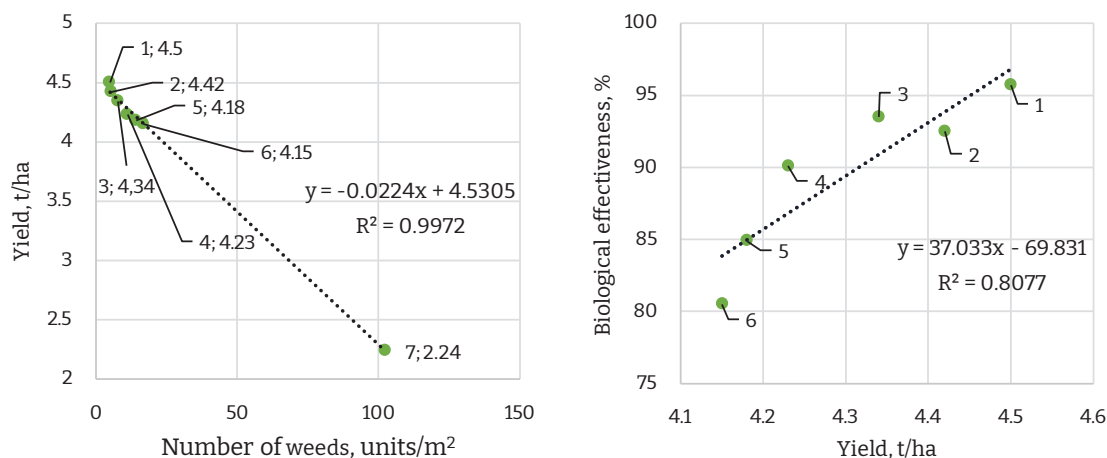


Figure 3. Spring barley yield and its dependence on the number of weeds and the biological effectiveness of herbicides

Note: 1, 2, 3, 4, 5, 6, 7 – experiment variant numbers, $LSD_{05} = 0.16$ t/ha

Thus, the results obtained differ from those of Tavaziva *et al.* [12] in the question of the effectiveness of herbicides against *Cirsium arvense* (L.) Scop at earlier stages of weed development (4 leaves). The highest efficiency in studies against this type of weed was achieved when 8-12 leaves are formed. Data were obtained on the high biological efficiency of Kvelex at a rate of 0.05 l/ha against *Polygonum convolvulus* L. and *Galium aparine* L. were consistent with the results obtained by M. Yanev [17]. Data on the biological effectiveness of Lancelot 450 WG vs. *Cirsium arvense* (L.) Scop at the level of 86-97.3%, depending on the application period, different from the results obtained by Zargar *et al.* [18], which indicate a small level of control of this weed.

The conclusions of the conducted studies are consistent with the data obtained by Kieloch & Marczewska-Kolasa [11], which indicate the highest yield of spring barley when applying herbicides at earlier stages of crop development and annual dicotyledonous weeds. Studies on the effectiveness of herbicides for applying spring barley to different phases of development and their impact on crop yield, conducted by other researchers [19; 20] in different soil and climatic zones, also provided similar results.

Reduction of spring barley yield in the presence of weeds in the range of 90-114 units/m² ranges from 85.8% to 101.1% depending on the timing of herbicide application, which is much higher than according to L. Pelekh [1], in whose studies this figure ranged from 49.0 to 62.4%. However, to evaluate these results, more research will be needed over more years to cover greater diversity in weather conditions.

CONCLUSIONS

The biological effectiveness of the studied drugs against annual and perennial weeds significantly depended on the time of their application. The highest effectiveness against some annual species was for the introduction of Kvelex and Lancelot 450 WG in the early stages of weed development and was, respectively, against: *Cenopodium album* L. – 95.9% and 91.0%; *Polygonum convolvulus* L. – 95.6% and 95.0%; *Amaranthus retroflexus* L. – 94.9% and 97.3%. Thus, in case of annual contamination with these species, it is advisable to apply herbicides during the formation of cotyledons-first pair of real leaves in weeds corresponding to the BBCH 18 phase of spring barley.

Better control of perennial species – *Cirsium arvense* (L.) Scop. and *Sonchus arvensis* L. was observed when introducing drugs in the second and third terms. Therefore, with a significant number of thistles, to completely eradicate them, it is advisable to use these drugs in the presence of 8-12 leaves in weeds, which corresponds to the BBCH 25-30 development phase of spring barley. The effectiveness of the drugs was almost 100%.

On control *Stellaria media* (L.) Vill., *Melandrium album* Mill, *Persicaria lapathifolia* L., *Polygonum convolvulus* L., *Galium aparine* L., the timing of drug administration did not affect.

Despite generally worse control of perennial weeds per application of Kvelex and Lancelot 450 WG in the BBCH 18 phase of spring barley, these variants provided a reliably high crop yield – at the level of 4.5 and 4.42 t/ha. Thus, to fully mitigate the harmful effects of weeds on the yield of spring barley, it is advisable to apply Kvelex and Lancelot 450 WG at the early stages of crop development,

which will maximise the destruction of young weeds and significantly suppress perennial weeds.

Considering the high harmfulness of dicotyledonous and monocotyledonous perennial and annual weed species, studies to determine the biological efficacy and selectivity to the culture of tank mixtures of Kvelex and Lancelot 450 WG with graminicides based

on pinoxaden and phenoxaprop-P-ethyl will be promising. Moreover, it is advisable to conduct experiments on the joint use of the studied herbicides with morphoregulators based on chlormequat chloride trinexapac-ethyl, calcium prohexadione, mepiquat chloride, and ethephone for introduction into different phases of crop development.

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Семен Петрович Танчик, Олександр Сергійович Павлов, Антоніна Іванівна Бабенко

Національний університет біоресурсів і природокористування
03041, вул. Героїв Оборони, 15, м. Київ, Україна

Контроль бур'янів у посівах ячменю ярого за різних термінів застосування гербіцидів

Анотація. Бур'яни можуть суттєво зменшити урожайність ячменю ярого, тому актуальними є дослідження щодо визначення оптимальних строків внесення гербіцидів на основі сучасних діючих речовин з метою контролювання широкого спектру бур'янів. У зв'язку з цим дана стаття спрямована на дослідження ефективності препарату Квелекс на основі нових діючих речовин галаоксифен-метилу та флорасуламу порівняно з Ланцелот 450 WG проти малорічних та багаторічних дводольних бур'янів за внесення в різні фази розвитку культури та бур'янів в посівах ячменю ярого. Провідними підходами щодо вирішення цієї проблеми є проведення польових досліджень для визначення біологічної ефективності гербіцидних варіантів та статистичні методи (дисперсійний, кореляційний) – для визначення точності та достовірності експериментальної інформації. У результаті проведених досліджень з'ясовано, що в разі забур'яненості малорічними бур'янами *Cenopodium album* L., *Polygonum convolvulus* L., *Amaranthus retroflexus* L. та ін. обприскування гербіцидами найкраще проводити у фазу сім'ядолей – першої пари справжніх листків бур'янів, що відповідає фазі ВВСН 18 ячменю ярого. Це забезпечило найвищу ефективність проти цих видів на рівні 95,5 % для Квелекс та 94,4 – Ланцелот, 450 WG. Але за цієї фази знижується ефективність проти *Cirsium arvense* (L.) Scop. та *Sonchus arvensis* L. до відповідно 94 % та 86,6 %. Проте, осоти суттєво пригнічуються та в подальшому не становлять конкуренції для культури, що дозволило отримати достовірно найвищу врожайність ячменю ярого (4,5 т/га за внесення Квелекс та 4,42 т/га за використання Ланцелот, 450 WG) порівняно з варіантами, де гербіциди вносили у фази ВВСН 25-30 культури. Матеріали статті становлять практичну цінність для аграріїв щодо вибору фази розвитку бур'янів та культури під час внесення гербіцидів у посівах ячменю ярого

Ключові слова: Квелекс, Ланцелот, 450 WG, біологічна ефективність, урожайність

Oleh Tkach^{1*}, Vasyl Ovcharuk¹, Oleh Ovcharuk², Bohdan Mazurenko², Marcin Niemiec³

¹Higher Educational Institution "Podillia State University"
32316, 12 Shevchenko Str., Kamianets-Podilskyi, Ukraine

²National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

³University of Agriculture in Krakow
31-120, 21 Mickiewicza Ave., Krakow, Poland

Chemical composition of chicory root ash (*Cichorium intybus* L.) depending on the yield level

Abstract. The world practice of growing chicory root is ineffective for Ukrainian phenotypic forms of varieties, since the weight and shape of the root crop, and the accumulation of ash elements in the plant, differ from modern forms. The purpose of the study was to establish the features of accumulation of the main ash macro- and microelements in the root crop and leaf mass of chicory of the Umanskyi-99 variety, considering the different background of mineral nutrition, the size of root crops, and yield levels. The study was conducted on the premises of the Khmelnytskyi state agricultural experimental station of the Podillia Institute of Feed Research and Agriculture of the National Academy of Sciences of Ukraine. The leaf mass (petioles and leaf blade) and root crops were combusted, and then the content of potassium, phosphorus, calcium, magnesium, sodium, and a complex of meso- and microelements (Ba, Si, Fe, Mn, Al, Cu, B, Cr, Zn, Co) was determined in the ash using a spectrograph, or using standardised methods. The content of the studied trace elements in leaves, roots, and petioles ranged from 1×10^{-4} up to $1 \times 10^{-2}\%$. The specific removal of nutrients to form 8.1 t/ha of root dry matter and the corresponding amount of by-products was 216.6 kg/ha of nitrogen, 79.6 kg/ha of phosphorus, 277.9 kg/ha of potassium, 92.7 kg/ha of calcium, 88 kg/ha of magnesium, and 109.3 kg/ha of sodium. A significant part of macronutrients accumulated in the leaf mass, so about 60-84% of the removed elements were returned to the soil. It is established that the chemical composition of ash of different-sized and different-yielding root crops differs. The content of phosphorus and potassium in root crops at an average yield level is the lowest among the samples under study, and at a high yield, it significantly exceeds low-yielding ones. Therefore, for optimal removal of nutrients when growing chicory root crops, a fertiliser system should be developed to obtain commercial roots at the level of average yield, which would reduce the specific removal of phosphorus and potassium. The practical significance of the results obtained is to highlight the features of the removal of the main macronutrients by chicory root plants, which is the basis for developing an effective fertiliser system for a high planned yield and choosing a strategy for using by-products (leaf mass) as a source of immobilised nitrogen, phosphorus, and potassium

Keywords: combustion of vegetative organs, different quality of root crops, spectrogram, nitrogen forms

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*Corresponding author

INTRODUCTION

Chicory root is a promising technical crop with a high yield potential and undemanding cultivation technology. The advantage of chicory root crops is the presence in their composition of a polymer carbohydrate – inulin, which consists of glucose residues and belongs to dietary fibre by its nutritional value [1-3]. From a technological standpoint, inulin does not require chemical hydrolysis to start alcoholic fermentation in yeast culture, so the cost of producing alcohol from chicory is 1.2-1.5 times less compared to starch [4; 5]. The content of inulin in chicory roots is 42-76 g/100 g of dry matter [6] and varies depending on the growing conditions, technology elements, root size, and fertiliser system [7].

The development of root crop yields closely depends on the chemical composition of the product and the availability of nutrients in the soil. In contrast to sugar beet, the ratio of leaf and root fractions in the plant can vary significantly [8], so it is necessary to determine the content and gross removal of the main macro-, meso-, and microelements by root crops and the leaf mass of chicory, to establish the dependence of this removal between the yield and economic characteristics of the roots (size).

Chicory growing conditions have a decisive influence on the content of macro- and mesoelements in individual plant organs. G.L. Lenz *et al.* [9] indicated that the concentration of phosphorus and potassium in the leaves varied depending on the shape of the substrate and the time of cultivation, i.e., low photoperiodicity. Overall, they noted that the phosphorus content of chicory leaves ranged from 1.5 to 2.2 g/kg of crude weight, and potassium – from 41 to 76 g/kg of crude weight. However, the results obtained are not entirely representative, since the phenology of the studied varieties in terms of size and structure of root vegetables does not correspond to those grown in Ukraine. In aquaponics conditions, the water content of tissues is high, and the dry matter content is low (at the level of 7-8%), so in the field, the availability of individual elements and their assimilation in the aboveground part may vary.

The ash content of chicory roots varies depending on the moisture content. Samples obtained and described by G. Jan [10] contained 58% moisture, and the content of other components in terms of dry weight was 8.12% ash and 27.3% raw fibres. According to the results of other studies [3; 11], chicory roots with a moisture content of 75-76% contain 4.25-4.45% raw ash in terms of dry weight and about 30% insoluble dietary fibre. The ash content in the dry matter of the roots reached 10.9% in samples containing 87.6% moisture [12], that is, the ash content of the dry matter decreases with the accumulation of dry matter during the growing season.

The total ash content in the leaf samples obtained [10; 13] ranged from 15.1-18.7% of the dry weight, with a tendency to increase with the ageing of these organs. The ash content in the raw mass in the leaves ranges

from 1.65-2.14%, depending on the conditions of the year and the time of harvest [14]. With an average ash content of 1.78 g/100 g of leaves, almost a third was occupied by potassium (699 mg/100 g), high sodium (75.9 mg/100 g), calcium (100 mg/100 g), and magnesium (25.5 mg/100 g). The phosphorus content of chicory leaves is relatively low compared to other members of the *Asteraceae* family and is only 47 mg/100 g of raw weight [15].

Chicory roots can contain up to 73% ash [16], which includes a variety of minerals, including calcium, magnesium, and sodium, and the content of these compounds exceeds many herbaceous plants [17], which makes chicory tops a valuable animal feed. However, chicory can accumulate a significant part of heavy metals in the leaves, for example, the concentration of chromium, aluminium, cadmium, nickel, and cobalt [18], can exceed the limit standards, and the use of such products in food is not allowed. The content of calcium and magnesium in chicory leaves is 6-17 g/kg and 1.4-2.2 g/kg of raw mass, but due to the high digestibility of silicon (more than 4% by weight of ash) and trace elements, chicory leaves can only be consumed from products grown on substrates without an excess of heavy metals [9; 19].

Global studies of the chemical composition of chicory are based on local forms and varieties, so they are not always representative. Modern varieties of chicory root are characterised by an increase in the proportion of roots in the total biomass of the plant, so the content of macro- and microelements observed in wild plants no longer corresponds to cultivated forms for obtaining roots. Since the chemical composition of roots and leaves is closely correlated with the removal of these nutrients, the study of the chemical composition of plants of programmed parameters allows optimising the cultivation technology, especially in terms of developing a fertiliser system.

The purpose of the study was to investigate changes in the chemical composition of chicory root plants in various organs (root crops, leaves, petioles) depending on the yield and fractional composition of root crops.

MATERIALS AND METHODS

The initial material for assessing the chemical composition of chicory was obtained during 2014-2016 when growing the Umanskyi-99 chicory root variety on the premises of the Khmelnytskyi state agricultural experimental station of the Podillia Institute of Feed Research and Agriculture of the National Academy of Sciences of Ukraine. The soil of the experimental site was podzolised chernozem, large-dusty-medium-loam low-humus. The thickness of the humus horizon was 110-120 cm, the humus content was 2.2-2.8% (according to Tyurin). The supply of soil with nutrients was average: 0.157-0.169% of total nitrogen (according to Keldal), 16.5 mg of mobile phosphorus per 100 g of soil, and 11.5 mg of exchange potassium per 100 g of soil. The content of mobile forms

of macronutrients and humus was established annually in the laboratory of the Khmelnytskyi branch of the Institute of Soil Protection of Ukraine in accordance with DSTU 4289:2004 [20].

The total amount of precipitation during the growing season (April-September) in 2014 was 773.1 mm (283.2 mm more than the long-term value), in 2015 – 510.1 mm, and in 2016 – 529.9 mm. The average temperature of the growing season in 2014 was 17.7°C (+2.7% of the long-term), in 2015 – 18.7°C (+3.7°C), and in 2016 – 17.9°C. According to weather conditions, all years were characterised by warm weather and high precipitation, which is sufficient to form high yields of chicory, so the weather was not a limiting factor.

To obtain different-quality root crops, a one-factor field experiment was laid: factor A – the norm of mineral fertilisers: without fertilisers (Control), $N_{40}P_{60}K_{80}$, $N_{80}P_{120}K_{160}$, $N_{120}P_{140}K_{180}$, $N_{160}P_{180}K_{220}$. Model chicory variety – Umanskyi-99. The technology of growing chicory root is typical for the forest-steppe zone of Ukraine, with the exception of the factors under study. Its predecessor was winter wheat. After harvesting the predecessor, stubble was shelled with a Husker LDG-10 disk to a depth of 5-6 cm. Phosphorous (double superphosphate, 43% P_2O_5) and potash fertilisers (potash salt, 60% K_2O) was fully applied in autumn for ploughing. Ploughing was carried out in the first ten days of September of each research year to a depth of 25-27 cm. In spring, when the soil moisture reached below 60% of the pre-irrigation humidity, early spring harrowing was carried out to a depth of 4-6 cm, and on the day of sowing, pre-sowing cultivation was carried out to a depth of 2-4 cm. Nitrogen fertilisers (ammonium nitrate, 34.4% N) were applied in full for pre-sowing cultivation according to the research scheme. Sowing was carried out to a depth of 1-1.5 with SZF-3600-T seed drill at a soil temperature in a layer of 0-5 cm at the level of +5...+7°C (April 15, 2014, April 22, 2015, and April 18, 2016). Drained seeds of the Umanskyi-99 variety were sown in a quantitative norm of 250 thousand germinating seeds per hectare with a row spacing of 45 cm. Plant protection products were not used on chicory crops. The area of the accounting experimental plot was 25 m², total area – 35 m².

Samples of root crops and the aboveground part were taken diagonally across the experimental plot. Plant samples were taken during the technical ripeness phase of root crops with a viable leaf mass. The mass of the total sample for laboratory tests was: small root crops – not less than 1 kg; large ones – not less than 3 kg.

Chemical quality indicators of root crops and leaves were determined in fresh samples in accordance with generally accepted standard methods: dry matter content – on

RPL 3M refractometer according to DSTU 8402:2015 [21]; protein nitrogen according to Bartstein [22], total nitrogen according to Kendal [22]; potassium by flame photometer according to Ginzburg [22]; phosphorus by colorimetric method, other chemical elements by spectral analysis. The content of phosphorus, potassium, calcium, magnesium, and sodium in dry ash (excluding nitrogen) was determined using a spectrograph.

The alkalinity of ash (expressed in mg 0.1H of hydrochloric acid) was determined by titration of ash contained in 100 g of dry matter to neutralise alkaline elements.

Comparison of averages and determination of the materiality of the difference was carried out using the Student's t-test at the level of 95% significance.

RESULTS AND DISCUSSION

The chemical composition of chicory root in the phase of technical ripeness of root crops allows assessing the effectiveness of the fertiliser system and its contribution to crop development. The content of individual nutrients in products is the result of a complex influence of growing conditions, individual elements of the technology, and fertiliser system. Weather conditions and the chemical composition of the soil of the experimental site affect the chemical composition of individual plant organs, so there may be a certain difference between products grown in different conditions.

The content of individual chemical elements in plants of the Umanskyi-99 variety varied depending on the organ (Table 1). The content of phosphorus and potassium in the raw ash of the chicory leaf blade significantly exceeded the indicators of root crops (76% more phosphorus and 33.3% more potassium). The phosphorus content in the leaf blade reached 3.8% of the total mass of raw ash, while in root crops and cuttings, its content was significantly lower – 2.15 and 1.5%, respectively. The potassium content in the raw ash of the leaf blade reached 20%, and in the petioles – 17.0%, while the root crop contained 15%, which is explained by its role as a transport element, so in the zones of active formations of dry matter (petioles and leaves) during this period it will always be less. The content of calcium (Ca) in the raw ash of root crops and petioles did not differ significantly (4.5-5.6%), and it increased significantly in the leaf blade (8.8%). A similar situation was repeated with magnesium, but the gross content was on average 40-50% less than that of calcium. The highest silicon content of chicory was in root crops – 5.1% by weight of raw ash, then in the leaves its content was slightly less – 4.0%, but this element in the petioles was twice less. The sodium content in root crops was several times less than in petioles or leaves.

Table 1. Chemical composition of raw ash of conditioned chicory plants of the Umanskyi-99 variety, % (average for 2014-2016)

Chemical element	Plant organ		
	Root crop	Leaf blade	Petioles
P	2.15 ^b	3.8 ^a	1.5 ^b
K	15.0 ^b	20.0 ^a	17 ^{ab}
Ca	4.5 ^a	8.8 ^b	5.6 ^a
Mg	2.5 ^a	5.6 ^b	2.3 ^a
Ba	0.03	0.05	0.01
Si	5.1 ^a	4.0 ^a	2.5 ^b
Na	1.5 ^a	4.4 ^b	5.5 ^b
Fe	0.1	0.5	0.3
Mn	0.04	0.05	0.03
Al	0.1	0.01	5×10 ⁻³
Cu	5×10 ⁻⁴	3×10 ⁻³	1×10 ⁻³
B*	3×10 ⁻³	5×10 ⁻³	3×10 ⁻³
Cr*	2×10 ⁻³	2×10 ⁻³	2×10 ⁻³
Zn*	4×10 ⁻⁴	8×10 ⁻⁴	1×10 ⁻⁴
Co*	1×10 ⁻³	2×10 ⁻³	1×10 ⁻³

Note: indexes ^{a, b, c} horizontally indicate the presence/absence of a significant difference between the options according to the Student's criterion. The same letters indicate that there is no difference between the options. It is used only for macronutrients P, K, Ca, Mg, Si, Na. *The content of Cu, B, Cr, Co is set with an accuracy of 1×10⁻³ and Zn to 1×10⁻⁴

The content of trace elements in the chicory plant also varied depending on the location. Consequently, the iron content in root crops was 5 times lower than in the leaf blade and 3 times lower than in petioles, and the manganese content in different organs varied by 0.01% (from 0.03% in the ash of petioles to 0.05% in the root crop). Most aluminium accumulated in root crops – 0.1%, while it was 10 times less in leaves (0.01%), and 20 times less in petioles. The content of boron (B), copper (Cu), and zinc (Zn) in the leaf blade in some cases was more than 2 times higher than their accumulation in petioles

and root crops, while the concentration of chromium and cobalt in various organs of chicory plants did not vary significantly.

The accumulation of macronutrients in the root crop and leaf mass during the growing season has a close direct correlation with the removal of nutrients, so it can characterise the effectiveness of the applied fertiliser system. The content of the main macro- and mesoelements in chicory plants when forming a yield of 13.3 t/ha of dry biomass (8.1 t/ha of dry root mass and 5.2 t/ha of dry leaf mass) is shown in Table 2.

Table 2. Mineral content in chicory plants of the Umanskyi-99 variety (average for 2014-2016)

Mineral substance	Root vegetable				Leaf mass				Total biomass content, kg/ha
	Spectrogram indicators	Element content in dry ash, %	Element content in dry mass, %	Content in root crops, kg/ha	Spectrogram indicators	Element content in dry ash, %	Element content in dry mass, %	Leaf content, kg/ha	
Nitrogen (N)	-	-	1.07	86.9	-	-	2.49	129.7	216.6
Phosphorus (P)	4	9.2	0.39	31.4	2.5	5.7	0.92	48.2	79.6
Potassium (K)	18	21.7	0.91	74.1	20	24.1	3.90	203.8	277.9
Calcium (Ca)	4.5	6.3	0.27	21.6	6	8.4	1.36	71.1	92.7
Magnesium (Mg)	2.5	4.1	0.17	14	6	10	1.42	74.0	88.0
Sodium (Na)	5	10.7	0.45	36.6	4	8.6	1.39	72.7	109.3

It was found that root crops in dry ash contained the most potassium – 21.7%, which in terms of dry matter was 0.91%. The potassium content in the leaf mass was 24.1% by weight of dry ash and 3.9% by dry weight. In the absolute removal of potassium as a food element, chicory crops accumulated 277.9 kg/ha of this element during the growing season – 74.1 kg in root crops and 203.8 kg in leaves.

The phosphorus content in the dry ash of root crops was 9.2%, and in the dry mass, respectively, 0.39%, so the total accumulation of this element was 31.4 kg/ha in the roots. In total, 48.2 kg/ha of phosphorus accumulated in the leaf mass, while the content in dry ash and dry mass was 5.7 and 0.92%, respectively. In total, during the growing season, chicory plants removed 79.6 kg/ha of phosphorus from the field, but 48.2 kg/ha (60.6%) of this element was returned together with the leaf mass, so the total need for this element for growth and development during the growing season can be met with a small amount of phosphorous fertilisers in an easily accessible form with a high content of the element of nutrition in the soil.

Since nitrogen does not belong to ash elements, its content was determined only from the dry mass by alternative methods. It was found that the dry weight of root crops contained 1.07% of nitrogen, and in total 86.9 kg/ha of nitrogen was accumulated, and in the leaf mass respectively 2.49% and 129.7 kg/ha. In general, chicory crops produced 216.6 kg/ha of nitrogen during the growing season, of which 86.9 kg/ha was irrevocable, so this should be considered when developing a fertiliser system for the next crop.

The removal of mesoelements of calcium (Ca) and magnesium (Mg) was 92.7 and 88 kg/ha during the growing season, but their localisation depended on the plant organ because a significant proportion (77% and 84%) of these elements were contained in the leaf mass, and with the main products (root) a small part was removed, so it is not necessary to purposefully apply fertilisers to compensate for them. The calcium content in root crops was 6.3% by weight of dry ash and 0.27% of dry matter, and during the growing season, 21.6 kg/ha was removed.

At the same time, the leaf mass contained 8.4% calcium by weight of dry ash and 1.36% by total dry weight, and the removal reached 71.1 kg/ha.

The magnesium content in root crops was less than calcium – 4.1% by weight of dry ash and 0.17% by dry weight, respectively, only 14 kg/ha of magnesium is required for the development of 8.1 t/ha of dry biomass of root crops. The content of magnesium in the leaf mass significantly exceeded its concentration in root crops – 10% by weight of dry ash and 1.42% in dry mass, so for the development of the planned level of yield of leaf mass, 74 kg/ha of magnesium is needed, which is 84% of the total need for this element for the plant during the growing season.

Sodium plays an important physiological role in plants, so it is absorbed from the soil and accumulates in the roots in an average ratio of 1:2 relative to potassium. The Na concentration in root crops reached 10.7% of dry ash and 0.45% of the dry weight of the plant, and 36.6 kg/ha accumulated in root crops. The ash of the leaf mass contained 8.6% sodium, which corresponded to 1.39% of the dry weight of the plant, and during the growing season 72.7 kg/ha of this element was carried out with leaves (in total, the plant – 109.3 kg/ha).

The removal of the main nutrients with the main products (root) from the field ranged from 16% for magnesium to 40% for nitrogen and phosphorus, but for the effective development and accumulation of dry matter in chicory, a large amount of available nutrients (216.6 kg/ha of nitrogen, 79.6 kg/ha of phosphorus and 277.9 kg/ha of potassium) is necessary, which are returned to the soil after harvesting.

The chemical composition of root crops and leaves of chicory of the Umanskyi-99 variety was different, since the ratio of different groups of chemicals (proteins, fats, carbohydrates, ash substances) is different. The root crop in chicory performs a storage role – assimilation of carbohydrates, in particular inulin, while the ash content, in this case, decreased by 3.8 times compared to the leaves (Table 3).

Table 3. Composition of raw ash of the Umanskyi-99 chicory variety, % per dry matter (average for 2014-2016)

Plant organs	Raw ash	Cl	Ca	Na	Mg	Fe
Root crops	3.9	0.2	2.13	0.4	0.26	0.04
Leaves	14.9	1.26	3.9	2.1	1.7	0.08

In leaves, as organs of active assimilation of dry substances, the content of ash elements is high, and the concentration of individual elements (Mg, Fe) is increased, because they are part of the photosynthetic apparatus of the plant. The content of raw ash in the leaves was 14.9%, which is almost 4 times higher than its content in root vegetables, while the concentration of calcium (Ca) and iron (Fe) was only doubled. The concentration of chlorine and sodium in various organs of chicory plants is proportional to the content of raw ash, and the content of magnesium in the leaves was 71% higher than the indicator of

roots in terms of a unit of raw ash. Chicory roots are the main product in the cultivation of this crop, so the content of macro- and mesoelements in them is an important characteristic for determining the optimal need of plants for fertilisers at different yield levels. The content of crude ash in dry chicory biomass depended on the level of yield (Table 4), but an inverse correlation was observed between yield and ash content, since the increase in biomass is mainly conditioned by the accumulation of carbohydrates (inulin) in cambial tissue, and ash elements are localised in meristems that do not grow intensively.

Table 4. Chemical composition of Umansky-99 chicory root crops depending on different yield levels (average 2014-2016)

Yield, t/ha	Content, % per dry matter						
	Raw ash	N	P	K	Ca	Mg	Na
Low (15-25)	4.05 ^a	1.29 ^a	0.408 ^a	0.381 ^a	1.03 ^a	0.245 ^a	0.197 ^a
Average (30-35)	3.97 ^a	1.18 ^{ab}	0.349 ^b	0.358 ^a	1.37 ^b	0.230 ^a	0.275 ^b
High (40 or more)	3.57 ^b	1.10 ^b	0.475 ^c	0.44 ^b	1.42 ^b	0.225 ^a	0.291 ^b

Note: indexes a, b, c vertically indicate the presence/absence of a significant difference between the options according to the Student's criterion. The same letters indicate that there is no difference between the options

The content of raw ash in chicory root crops did not differ significantly at low and medium yields (4.05% and 3.97%, respectively), but it significantly decreased by 0.40-0.48% according to the Student's criterion with a yield of more than 40 t/ha. The nitrogen content also decreased with increasing yields, gradually and without significant differences between adjacent groups, however, the difference between low- and high-yield root crops was significant (1.29 and 1.10%, respectively). The phosphorus content in root crops at a low yield was 0.408%, at an average significantly decreased (up to 0.349%), and at a high significantly increased – 0.475%, a similar effect was observed with potassium, so it can be assumed that at a high yield (due to high rates of mineral fertilisers) there is an additional accumulation of these macronutrients without an equivalent physiological role, that is, ballast. With an average (30-35 t/ha) and a high level of yield (40 t/ha or more), the content of calcium and sodium did not differ significantly, and with a low level of yield, their content was significantly lower according to the Student's criterion

and amounted to 1.03% and 0.197% in terms of dry matter, respectively. The magnesium content in root crops ranged from 0.225% with a yield of 40 t/ha of root crops and more to 0.245% in variants with a low yield level (15-25 t/ha), but statistically, these indicators did not differ according to the Student's criterion, because the average error exceeded the difference between the values.

When growing chicory root crops under the same conditions, random differentiation of root crop development occurs, so small, average, and large root crops are formed. The size and weight of such root crops in each individual case were different depending on the average yield level and the year of research. Average root crops included typical root crops weighing 100-250 g (depending on the conditions of the year and yield), small ones included root crops that differed from the average fraction by more than 50% by weight, and large ones – those that exceeded 100%. The content of macronutrients and their oxides in the ash of these root crops varies depending on their size (Table 5).

Table 5. Composition of raw ash in different groups of chicory root crops grown under the same conditions, % by dry weight (average for 2014-2016)

Chemical compound	Gradation of root crops by size		
	Large	Average	Small
P ₂ O ₅	1.46 ^a	1.30 ^b	1.21 ^b
Na ₂ O	0.30 ^a	0.06 ^b	0.06 ^b
K ₂ O + Na ₂ O	1.77 ^a	1.46 ^b	1.27 ^c
Ca	0.21 ^a	0.24 ^{ab}	0.27 ^b
MgO	0.31 ^a	0.32 ^a	0.32 ^a
Ca + MgO	0.52 ^a	0.56 ^{ab}	0.59 ^b
F ₂ O ₃	0.23 ^a	0.21 ^a	0.20 ^a
MnO	0.009 ^a	0.01 ^a	0.041 ^b
Cl	0.24 ^a	0.18 ^a	0.10 ^b
SO ₂	0.24 ^a	0.26 ^a	0.26 ^a
Raw ash	27.1 ^a	28.6 ^a	37.2 ^b

Note: indexes a, b, c horizontally indicate the presence/absence of a significant difference between the options according to the Student's criterion. The same letters indicate that there is no difference between the options

Content of P₂O₅ in the raw ash of large root crops was significantly higher (1.46%) than in average and small ones. Na₂O concentration in large root crops was 5 times higher (0.3%) than in average and small ones (0.06%).

Since potassium and sodium (K₂O + Na₂O) are absorbed by the plant at the same time and have a similar

physiological role, then their sum indicates the growth efficiency of each individual plant. In large root crops, the sum of these compounds was 1.77%, while in average-sized crops – 1.46%, and in small ones – 1.27%. A higher amount of these compounds in medium-sized root crops than in small ones indicates a greater accumulation

of potassium at the same sodium level, therefore, it is potassium among these substances that has a determining effect on the size of the root crop.

The concentration of calcium in large root crops was significantly lower (0.21%) than in small ones (0.27%), which may be conditioned by the concentration of cytosolic-free calcium $[Ca^{2+}]_{cyt}$, which is a signal complex of the plant's stress state. At the same time, a small relative difference (28.5%) indicates that the main reason for the increase in calcium concentration in the plant is the overall increase in raw ash in small root crops compared to large ones, and not a stress factor, which is generally consistent with the results obtained by K.A. Wilkins [23]. Calcium in the soil promotes the absorption of Mg^{2+} ions, however, it does not lead to the accumulation of surpluses, which is observed in the experiment, since the MgO content is almost independent of the size of the root crop, and the difference is statistically insignificant. The nature of this phenomenon is the high mobility of magnesium in the plant organism and its localisation in the conducting vessels [24], so the stability of the concentration of this element in ash is evidence of homeostasis, while a significant difference (more than 25%) indicates the manifestation of stress and magnesium deficiency [25]. As a consequence of this indicator, it can be argued that the differentiation of root crop size is not conditioned by abiotic stress, which affects the growth of the root system and magnesium absorption [26].

The content of F_2O_3 almost does not differ depending on the size, and the maximum difference between the indicators did not exceed 0.03% (0.23% for large root crops and 0.20-0.21% for average and small ones). The concentration of MnO, on the contrary, increases with a decrease in the root crop – small root crops contain 4 times more of it than small and average-sized ones. The chlorine content in large root crops is 0.24%, slightly decreases in average ones (0.18%), and significantly less

accumulates in small ones (0.1%). The sulphur content does not depend on the size of the root crop and was generally stable in the Umanskyi-99 variety – 0.24-0.26%.

In general, the content of raw ash was 27.1% in large root crops, and when the size of the root crop was reduced to small, it increased to 37.2%, since the main factor in increasing the root size is the accumulation of carbohydrates (inulin), so there is an inverse correlation between these indicators. Small root vegetables contain short-chain inulin molecules in their composition and generally form fewer carbohydrates, so the total ash content increases [27].

It was previously established that chicory of the Umanskyi-99 variety contains an average of 1.07% nitrogen in the dry mass of root crops and 2.49% nitrogen in the leaves (Table 2), but from a standpoint of production, it is important to know the efficiency of using this nitrogen. Nitrogen can be found in plants in two main forms – protein (a component of protein, amino acids, and polypeptides) and soluble (nitrates, ammonium form) [28]. The protein form is responsible for the quality and feed value of products, while the soluble form indicates the efficiency of nitrogen assimilation from the soil. The high content of soluble nitrogen in root crops of various sizes during the technical ripeness phase can be an indicator of the effectiveness of fertiliser application [29].

The total nitrogen content in the crude vegetative mass ranged from 0.44 to 0.50% (Table 6). In average and small root crops of low-yielding crops, the total nitrogen content was the lowest – 0.44%, which may indicate trophic problems, and in small root crops from high-yielding crops, this indicator approached the value of large root crops, which is evidence of a deviation in root development for morphological reasons [30]. Protein nitrogen in root crops is part of cells, while soluble nitrogen is a signal of an inefficient fertiliser system, since its excess in late phases of development does not affect the yield level [31].

Table 6. Nitrogen content and alkalinity of raw ash in chicory of the Umanskyi-99 variety, depending on the intensity of root crop growth (average 2014-2016)

Root crop group	Vegetative mass				Root crops			
	Nitrogen content in the crude mass, %			Ash alkalinity	Nitrogen content in the crude mass, %			Ash alkalinity
	Total	Protein	Soluble		Total	Protein	Soluble	
Large	0.50 ^a	0.31 ^a	0.19 ^{ab}	318	0.44 ^a	0.12 ^a	0.32 ^a	51
Average	0.44 ^b	0.28 ^{ab}	0.16 ^b	289	0.41 ^{ab}	0.13 ^a	0.28 ^{ab}	47
Small high-yielding plants	0.49 ^a	0.27 ^{abc}	0.22 ^a	298	0.42 ^{ab}	0.12 ^a	0.30 ^{ab}	72
Small low-yielding plants	0.44 ^b	0.23 ^c	0.21 ^a	273	0.39 ^b	0.13 ^a	0.26 ^b	57

Note: indexes ^{a, b, c} vertically indicate the presence/absence of a significant difference between the options according to the Student's criterion. The same letters indicate that there is no difference between the options

The highest value of protein nitrogen content was found in the leaves of large root crops (0.31%), and in average and small high-yielding crops it decreased to 0.28 and 0.27%, respectively, which is within the measurement error. Small low-yielding root crops contained 0.23%,

which is significantly less than in average and large ones, but not significantly compared to small high-yielding ones. The content of soluble nitrogen in average-sized root crops is the lowest – 0.16%, while in other groups of root crops it is significantly higher – 0.19-0.22%.

Chicory roots contain on average 11.1% less total nitrogen than the vegetative mass, but its content, depending on the size of the root, varied within narrower limits – 0.39-0.44%. The highest value of total nitrogen was found in large root crops (0.44%), and in small low-yielding crops it significantly decreased (0.39%), while in other groups it had an intermediate value and did not significantly differ from other indicators. The content of protein nitrogen in root crops almost did not vary and amounted to 0.12-0.13%, and with soluble nitrogen, the situation with total nitrogen (0.26-0.32%) was repeated.

CONCLUSIONS

The size of root crops and the level of chicory yield affected the chemical composition of root and leaf ash. The mineral composition and removal of nutrients by chicory root plants in root plants and leaves differed from each other. Nutrient content of root crops in raw mass P_2O_5 was 9.2%, while in leaves – 5.7%; K_2O – 21.7%, in leaves – 24.1%. According to the chemical composition of the chicory root plant and the intensity of its growth and high yield, a direct relationship was found with the yield of 15-25 t/ha, the content of raw ash was 4.05%, and with

an increase in yield to 40-45 t/ha and above – 3.57%. The specific removal of 8.1 t/ha of dry matter of the main product and its corresponding by-products was 216.6 kg/ha of nitrogen, 79.6 kg/ha of phosphorus, 277.9 kg/ha of potassium, 92.7 kg/ha of calcium, 88 kg/ha of magnesium, and 109.3 kg/ha of sodium. Irretrievable losses of food elements during the export of the main products amounted to 86.9 kg/ha of nitrogen, 31.4 kg/ha of phosphorus, and 74.1 kg/ha of potassium, so this should be considered to compensate for the next crop. Chicory accumulates a high concentration of ash elements in the leaf mass during the growing season, so an appropriate level of available nutrients should be provided for the generation of a high yield of root crops.

A promising area of further research is to investigate the features of accumulation of macro- and micro-elements by chicory plants, considering the differentiated basal and foliar application of fertilisers. The use of chicory for energy purposes allows growing raw materials on lands contaminated with heavy metals, so a wide geography of research on the chemical composition of root crops and other parts of the plant would expand the understanding of trophic mechanisms of ash element accumulation.

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**Олег Васильович Ткач¹, Василь Іванович Овчарук¹, Олег Васильович Овчарук²,
Богдан Олександрович Мазуренко², Марцін Немец³**

¹Заклад вищої освіти «Подільський державний університет»
32316, вул. Шевченка, 12, м. Кам'янець-Подільський, Україна

²Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна

³Сільськогосподарський університет ім. Гуго Коллонтая у Кракові
31-120, алея Міцкевича, 21, м. Краків, Україна

Хімічний склад золи рослин цикорію коренеплідного (*Cichorium intybus* L.) залежно від рівня врожайності

Анотація. Світова практика вирощування цикорію коренеплідного неефективна для українських фенотипових форм сортів, оскільки маса та форма коренеплоду, а також накопичення зольних елементів у рослині відмінне від сучасних форм. Мета роботи полягала у встановленні особливостей накопичення основних зольних макро- та мікроелементів у коренеплоді та листовій масі цикорію коренеплідного сорту Уманський-99 з врахуванням різного фону мінерального живлення, розміру коренеплодів та рівнів урожайності. Дослідження було проведене в умовах Хмельницької державної сільськогосподарської дослідної станції інституту кормів та сільського господарства Поділля НААН України. Листкова маса (черешки та листкова пластинка) та коренеплоди попередньо озолювалися, а потім в золі визначався вміст калію, фосфору, кальцію, магнію, натрію та комплексу мезо- і мікроелементів (Ba, Si, Fe, Mn, Al, Cu, B, Cr, Zn, Co) за допомогою спектрографа, або з застосуванням стандартизованих методів. Вміст досліджуваних мікроелементів у листках, коренях та черешках становив в межах від 1×10^{-4} до 1×10^{-2} %. Питомий вміст елементів живлення для формування 8,1 т/га сухої речовини коренів та відповідної кількості побічної продукції становив 216,6 кг/га азоту, 79,6 кг/га фосфору, 277,9 кг/га калію, 92,7 кг/га кальцію, 88 кг/га магнію та 109,3 кг/га натрію. Значна частина макроелементів акумулювалася у листовій масі, тому близько 60-84 % винесених елементів поверталось в ґрунт при зароблянні листової маси. Встановлено, що хімічний склад золи різнорозмірних та різноурожайних коренеплодів різниться. Вміст фосфору та калію у коренеплодах за середнього рівня врожайності найнижчий серед досліджених проб, а при високій врожайності суттєво перевищує низьковрожайні. Отже, для оптимального виносу елементів живлення при вирощуванні цикорію коренеплідного для отримання товарних коренів слід розробляти систему удобрення на рівень середньої врожайності, що дозволить зменшити питомий винос фосфору та калію. Практична цінність отриманих результатів полягає в освітленні особливостей виносу основних макроелементів рослинами цикорію коренеплідного, що є основою для розробки ефективної системи удобрення на високу планову урожайність та вибору стратегії використання побічної продукції (листової маси), як джерела іммобілізованих азоту, фосфору та калію

Ключові слова: озолення вегетативних органів, різноякісність коренеплодів, спектрограма, форми азоту

Larysa Semenko^{1*}, Serhii Veremeienko², Nataliia Yushchenko¹, Andrii Shatkovskiy³

¹National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

²National University of Water and Environmental Engineering
33028, 11 Soborna Str., Rivne, Ukraine

³Institute of Water Problems and Land Reclamation
03022, 37 Vasylykivska Str., Kyiv, Ukraine

Combination of effective use of irrigation and mineral nutrition for growing table potatoes

Abstract. The relevance of the study is conditioned by a decrease in the moisture supply of agricultural crops during the growing season due to climate changes and a tendency to reduce the moisture supply of agricultural crops. At the same time, the main approach to solving this problem is to combine fertigation with irrigation. The purpose of the study is to establish the dependence of the productivity of potatoes on the intensive farming system when using irrigation. Using the example of an agricultural enterprise typical for the region, the volume of nitrogen fertilisers applied to fully provide the crop during the growing season is estimated. To obtain scientific results, an analytical search was carried out and a field, laboratory, and statistical methods of processing the results were applied. As a result of the research, the distribution of nitrogen in comparison with losses in combination with organogenesis phases was optimised. To ensure communication between the plant, soil, and fertilisers, CAM 32 was used in doses of $N_{30}N_{15}$, which affected the structural indicators of the potato crop. When applying CAM 32 (N_{30}) + H_2O , the weight of tubers was obtained at the level of 4.65 kg/m², and the yield increase was 0.5 t/ha. When using nitrogen with $MgSO_4$, the yield increased to 1.5 t/ha compared to the control. In the process of transformation, it was found that the use of nitrogen nutrition CAM 32 (N_{15}) + $MgSO_4$ + $Ca(NO_3)_2$ + H_2O contributed to the most intensive development of tuber mass up to 4.85 kg/m² compared to the control – 4.6 kg/m². In the final product, an increase in the fraction was observed and amounted to more than 55 g/plant. The analysis of yield indicates a positive trend in the use of nitrogen nutrition, where the increase was 2.5 t/ha. The studied data can be applied by agricultural producers in the Forest-Steppe and Polissia zones to obtain high yield gains when growing potatoes

Keywords: agricultural resource potential, drip irrigation, nutrients, soil nutrient regime

INTRODUCTION

From 2009 to the present, the agricultural sector of Ukraine provides economic growth and export potential growth, mitigating negative trends observed in other sectors of the national economy. In the future, further growth of agricultural production is expected, considering the significant share of highly fertile soils, flat terrain, and favourable climatic conditions. Despite the high agricultural potential of Ukraine, the level of its use remains insufficient. The reason for this is, among other

things, the risks associated with a lack of moisture and adjustment of mineral nutrition.

Agriculture uses 70% of the total volume of fresh water [1; 2]. Ukraine is one of the least water-rich countries in Europe [3]. About 40% of the country's area belongs to the Steppe zone, which can be considered a zone of risky farming where moisture is the limiting factor. In general, more than 50% of the country's territory has insufficient moisture supply. Global climate changes,

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*Corresponding author

which have also affected Ukraine, only exacerbate this problem [4; 5]. The area of land belonging to the dry and very dry zones has significantly expanded. This includes 37% of arable land, while areas with sufficient moisture make up only 22.5% of arable land [6]. This trend will continue in the near future, which increases the urgency of expanding additional land irrigation.

In the second half of the 20th century, a powerful water management complex was created in Ukraine, providing only irrigation on an area of more than 2.5 million hectares [3; 6]. Since 2000, the area of irrigated land has significantly decreased. And since the beginning of 2014, the area of irrigated land has exceeded 500 thousand hectares [3]. The introduction of intensive technologies, increasing the productivity of agricultural crops by introducing new varieties of intensive type, and general intensification of production only exacerbate the problem of moisture supply of agricultural crops. Notably, during 2020-2022, there was a gradual revival of irrigation land reclamation. At the same time, this is already being done at a qualitatively new level, modern innovative technologies and new equipment are being introduced. In particular, areas with drip irrigation are expanding at a faster pace. Thus, according to [3], the area of land under drip irrigation exceeded 75 thousand hectares, of which about 53% are vegetables and melons, the rest are perennial plantings, row, technical, etc., and this trend will continue in the future. Despite the high cost, drip irrigation has a number of advantages that make this method of irrigation the most promising not only in Ukraine, but also in the world [7]. Significant advantages of drip irrigation include considerable savings in water and electricity. Electricity costs are reduced by 50-70%. Water consumption is reduced by up to 3.5 times, which is extremely important in the context of an increasing shortage of water resources. After all, more than 90% of the water supplied to the field is used by plants [8].

The adoption of the Strategy for the restoration and development of irrigation and drainage systems in Ukraine until 2030, approved by the Cabinet of Ministers [6], is an important step in intensifying work on the development of land reclamation and ensuring sustainable development of crop production in the south of the country [7]. The Strategy provides substantiation for the need for accelerated development of the land reclamation complex and defines the main strategic directions for its restoration on a modern basis. Over the past decades, the technical side has been developed quite deeply, and irrigation techniques and technologies have been studied on a modern basis. The issues of regulating the water regime of irrigated lands are considered in [6-9].

One of the main goals of the Strategy is to maintain the priority of ensuring environmental protection tasks, including the preservation and reproduction of soil fertility [6]. Therefore, one of the priority tasks should be to investigate the impact of modern irrigation technologies on the agroecological state of soils and ensure their high productivity. In the context of optimising the water supply of agricultural crops under irrigation conditions, the main factor that will determine productivity will be mineral nutrition of plants. Therefore, it is important to investigate the peculiarities of the development of a nutrient regime of soils in the conditions of using modern technologies of irrigation and cultivation of agricultural crops. Moreover, the consumption and removal of nutrients by agricultural crops on irrigated land increases significantly compared to dryland farming. Rational fertilisation is also an important measure to prevent soil degradation. After all, the analysis shows that in Ukraine there is a situation where irrational fertilisation is one of the reasons for the increased degradation of arable land [10; 11]. The analysis shows that the low level of application of organic and mineral fertilisers only compensates for the loss of nutrients used for crop formation by a third (Table 1).

Table 1. Removal of NPK by the marketable part of the crop and applied with fertilisers in Ukraine, 2018, million tonnes

Indicators	Nutrients		
	Nitrogen	Phosphorus	Potassium
Removal with the marketable part of the crop	1.849	0.727	0.566
Applied with fertilisers	1.431	0.402	0.318
Balance	-0.418	-0.325	-0.248

Insufficient fertiliser saturation is observed on both rainfed and irrigated lands [9]. The result is progressive dehumification and trophic degradation of soils. At the same time, the removal of nutrients from the soil under irrigation conditions is 5% higher than under dryland farming. Therefore, optimising the nutrient regime of irrigated soils and plant nutrition to preserve

soil fertility and obtain stable yields is a top priority. The norms of fertilisers applied under irrigation conditions are associated with a high level of removal of nutrients by the crop.

It should also be noted that the system of application of fertilisers in irrigation conditions is noticeably different from dryland farming. For example, fertigation

is widely used in drip irrigation [10]. During the period from 2005 to 2022, foliar top dressing of plants, precision farming technologies with regulation of mineral fertiliser doses, considering the spatial variability of the soil gust, became widespread. An important point is that the coefficients of use of nutrients from fertilisers and soil under irrigation conditions significantly differ from the indicators of rainfall conditions. All these aspects significantly affect the development of a fertiliser system for agricultural crops in the context of the use of innovative irrigation systems and intensive technologies. Most of these issues are currently insufficiently studied or practically not considered and require in-depth investigation. When calculating fertiliser application rates, coefficients developed about 50 years ago and mainly for rain conditions are used [7]. Therefore, they are not very suitable for modern conditions of intensive production.

An equally important component is the impact of irrigation on the agroecological state of soils. Since land reclamation radically changes the entire soil complex, affecting the development of the main soil regimes, properties, and even soil composition, it is important to study the effect of irrigation, and in particular, drip irrigation on soils. This is important both from the standpoint of preserving and reproducing soil fertility and rational and efficient use of irrigation water, fertilisers, pesticides, etc. In particular, the processes of migration, accumulation, and transformation of fertilisers in the soil during drip irrigation, spatial distribution of nutrient compounds in moisture zones, and possible loss of nutrients, mechanisms of absorption of nutrients by plants and dynamics of their accumulation in plants remain unexplored [11].

The introduction of modern innovative technologies on irrigated lands is not limited only to the use of modern equipment and irrigation technologies, as modern high-performance hybrids and intensive varieties, chemical agents, etc. are also used [12]. Modern farming systems are noticeably different from traditional ones, starting with a set of crop rotations and ending with a set of special measures. New varieties and hybrids of agricultural crops that are actively put into production during 2010-2020 differ significantly, both in terms of cultivation technologies and requirements for mineral nutrition. High productivity of agricultural crops, respectively, is ensured by optimal mineral nutrition of plants [13]. This requires clarification of the calculated norms of mineral and organic fertilisers based on the established coefficients of nutrient element utilisation for these crops. Ultimately, fertilisers and other agrochemicals account for 20% of the cost of growing agricultural crops, and their efficient and rational use will save money and reduce the burden on the environment [14].

The structure of the crop is a quantitative and qualitative reflection of the vital activity of plant elements and organs, which determine the size of the crop and reflect the interaction of the body and the external environment at these stages of growth and development [15]. Moreover, an analysis can determine what the yield value consists of, and synthesis – by what elements and at what share of their participation, a high yield is formed. Elements of the crop structure depend on many components and each of them has its own niche in the crop structure. The study of the potato yield structure shows a close correlation between the tuber yield and productivity components, primarily the weight of tubers, which, in turn, depends on the leaf surface area. The structure of the crop per unit area is determined by the number of tubers per plant (which depends on the number of stems in the bush and the number of tubers on one stem), the average weight of one tuber, and the number of plants per area [5; 13].

The purpose of the study consisted in determining the influence of potato feeding conditions and selecting types of nitrogen fertilisers for specific soil and climatic conditions through the formation of its productivity when using irrigation.

MATERIALS AND METHODS

Field studies were conducted in the Kyiv Oblast during 2020-2022 on a farm located in the Forest-Steppe of Ukraine, the climate of this territory is temperate continental. In this region, the duration of the growing season ranges from 198-204 days, which is equivalent to the amount of moisture that evaporates, so to obtain profitable yield increases with such an amount, the moisture content of the natural zone is insufficient [10; 16].

To ensure the harvest, tubers of the Karrera elite variety were planted, the fraction was 35-50 mm, and the varietal fraction was 100% [12].

According to the standard of Ukraine DSTU 4013-2001 "Varietal and sowing qualities of seed potatoes. TU", potato seeds of the first reproduction must meet certain requirements, which include the fractionality of tubers [17].

Observations were carried out throughout the growing season on the quality indicators of water that was used for watering potatoes. The analysis of water for irrigation was carried out in accordance with DSTU 8346:2015 [13]. The suitability of water for irrigation was estimated according to DSTU 2730-94 [18].

According to the set goal, an experiment was laid down according to the field experiment scheme (Table 2), which provided for the study of the effect of nitrogen nutrition on the development of the structure and growth of potato yield [19].

Table 2. Experiment scheme

No.	Fertiliser variant	BBCH phases
1	Control	–
2	CAM 32 (N ₃₀) + H ₂ O	BBCH 60-69
3	CAM 32 (N ₃₀) + MgSO ₄ + H ₂ O	BBCH 60-69 BBCH 71-79
4	CAM 32 (N ₁₅) + MgSO ₄ + Ca(NO ₃) ₂ + H ₂ O	BBCH 60-69 BBCH 71-79 BBCH 80-89

Before laying the experiments, the following operations were performed:

Autumn period:

- slitting 45 cm (John Deere 6195M + AGR 2.4);
- cultivation with a depth of 18-20 cm with the addition of KCl application rate of 300 kg/ha (John Deere 8300 + Peliper).

Spring period:

- mulching CAM 26 + 2.6% sulphur (Tecnomas Laser) 200 kg/ha;
- disking (John Deere 6195M + VADERSTAD) 5 cm;
- pre-planting cultivation for 12-18 cm and application of liquid complex fertilisers (8:24) 150 kg/ha (John Deere 8300 + Peliper);
- planting (John Deere 6195M + Grimme GL 34KL) 24.04.2021 + adding Selest top 1 l/ha and Bulbostim 1 l/t;
- after planting: introduction of MgSO₄ * 7H₂O (150 kg/ha) + CAM 26 + 2.6% sulphur 200 l/ha (Tecnomas Laser);
- hilling (John Deere 6195M + Grimme GF 75-4);
- application of Zenkor liquid (Tecnomas Laser) 600 g/ha
- introduction of CaCO₃ 100 kg/ha into the flowering phase (MVU-6 watering can);
- desiccation with Reglon Super v.r.k. (2 l/ha) with Inuma IAS 4030 EVOLUTION sprayer + John Deere tractor;
- mechanised potato harvesting unit ROPA + John Deere tractor.

According to the experiment, fertilisers were applied to critical phases of organogenesis that corresponded to BBCH phases of the culture. During the entire growing season, irrigation was carried out with drum-type irrigation systems using 5-fold irrigation with a spout rate of 250 m³/ha.

For a more accurate analysis of biometric indicators of potatoes, plant samples were selected during the growth and development phases: flowering, fruit development, and fruit ripening. To characterise the development of crops, such indicators as plant height, number of stems, number of tubers per plant, diameter were determined, and the crop structure was considered during the technical ripeness phase. All experiments were repeated three times.

RESULTS AND DISCUSSION

According to the conducted studies, when investigating the physiological parameters of potatoes, compliance with the lowest moisture capacity (MC) at the level of 80% affected the processes that occur in the plant. Applying irrigation and reformatting of agrotechnical measures in potato cultivation. All efforts aimed at accumulating moisture reserves in the soil under the condition of applying various forms of nitrogen fertilisers with irrigation water solved problems with the nutrient availability (Table 3).

Table 3. Influence of mineral fertiliser standards on the structural elements of Karrera potatoes

BBCH phases		Variants	Control	CAM 32 (N ₃₀) + H ₂ O	CAM 32 (N ₃₀) ++ MgSO ₄ + H ₂ O	CAM 32 (N ₁₅) + MgSO ₄ + Ca(NO ₃) ₂ + H ₂ O
Flowering phase (BBCH 60-69)	Number of stems, units/plant.		3	4	5	5
	Plant height, cm		52	54	56	53
	Number of tubers, units/plant.		9	12	15	13
	Average diameter of tubers, mm		30	40	45	45
Fruit development (BBCH 70-79)	Number of stems, units/plant.		4	4	5	5
	Plant height, cm		50	46	51	52
	Number of tubers, units/plant.		14	12	17	21
	Average diameter of tubers, mm		40	45	50	45
Fruit ripening (BBCH 80-89)	Number of stems, units/plant.		4	4	5	4
	Plant height, cm		43	40	48	44
	Number of tubers, units/plant.		13	9	19	15
	Average diameter of tubers, mm		55	50	55	55

When analysing the indicators of tubers of the Karrera variety during the flowering phase, the height of plants in the variants was in the range of 50-56 cm. The greatest height was observed during the flowering phase compared to subsequent growth and development phases. This can be explained by the fact that during this period, the vegetative mass of potatoes gives the greatest increase in green biomass during this phase. Highest height on the CAM 32 variant (N_{30}) + $MgSO_4$ + H_2O indicates a high supply of plants with mineral nutrition.

Researchers claim that the limiting indicator for crop development is the number of stems on the bush [20]. During the research, the statements of G.Y. Kornelyuk regarding dependences were confirmed. The dependence of the leaf index and leaf surface area per 1 ha also further affect the number and size of tubers. On variants with CAM 32 (N_{30}) + $MgSO_4$ + H_2O and CAM 32 (N_{15}) + $MgSO_4$ + $Ca(NO_3)_2$ + H_2O , it was 5 units/plant.

The future harvest is calculated by the number of tubers and is one of the most important indicators. The largest number of tubers was noted on the variant with the introduction of CAM 32 (N_{15}) + $MgSO_4$ + $Ca(NO_3)_2$ + H_2O and was 15 pieces per Bush. When analysing the fractionality of tubers, the effect on the quality of the potato crop was established. The conducted studies confirm the opinion of I.P. Bugaeva regarding the influence on the fractionality of potatoes [22].

A low percentage of the yield can be obtained by creating unhealthy, small, damaged tubers, and increasing the amount of a large fraction of potatoes. According to the study results, the indicators for variants with

the introduction of CAM 32 (N_{30}) + $MgSO_4$ + H_2O and CAM 32 (N_{15}) + $MgSO_4$ + $Ca(NO_3)_2$ + H_2O were 45 cm. At the phase change on BBCH 70-79, biometric indicators changed and ranged from 46 to 52 cm, this indicates intensive development of the root system and inhibition of green biomass growth. The number of tubers from the bush did not exceed 21 units when depositing CAM 32 (N_{15}) + $MgSO_4$ + $Ca(NO_3)_2$ + H_2O the smallest amount was noted on the option with the introduction of CAM 32 (N_{30}) + H_2O and was 12 units/plant. On the variant with CAM 32 (N_{30}) + $MgSO_4$ + H_2O and CAM 32 (N_{15}) + $MgSO_4$ + $Ca(NO_3)_2$ + H_2O increase in the diameter of tubers was observed and amounted to 50 and 45 mm, respectively. During the fruit ripening phase, the lowest plant height values were observed compared to the previous phases. The number of stems ranged from 5 units/plant. The largest number of tubers was observed on the variant with CAM 32 (N_{15}) + $MgSO_4$ + $Ca(NO_3)_2$ + H_2O was 22 units/plant, and the smallest number was observed in the variant CAM 32 (N_{30}) + H_2O – 12 units. But the fractional composition was the largest and was in the range of 45-55 mm.

It is established that the planting material of potatoes of the first reproduction is the key to a high and guaranteed harvest.

In the conducted studies, the structure of crop elements was determined according to which they were recorded. Thus, the main phase of technical ripeness was determined, the obtained values were characterised by the following scale: up to 40 mm, 40-55 mm, more than 55 mm. In addition, the total weight of tubers and their number were calculated (Table 4).

Table 4. Influence of mineral nutrition on the fractional composition and yield of Karrera potatoes

Variant	Number				Weight				Average weight of tubers, kg/m ²	Yield, t/ha
	Total, units/plant	Fraction <40, units/plant	Fraction 40-55, units/plant	Fraction >55, units/plant	Total, units/plant	Fraction <40, g/plant	Fraction 40-55, g/plant	Fraction >55, g/plant		
Control	23	6	7	10	1,950	650	500	800	4.60	46.0
CAM 32 (N_{30}) + H_2O	28	6	15	7	1,950	200	950	800	4.65	46.5
CAM 32 (N_{30}) + $MgSO_4$ + H_2O	33	13	16	4	1,875	325	950	600	4.75	47.5
CAM 32 (N_{15}) + $MgSO_4$ + $Ca(NO_3)_2$ + H_2O	26	8	9	10	2,100	250	575	1,275	4.85	48.5

The use of nitrogen nutrition in combination with irrigation in the cultivation of potatoes increased its yield. Thus, the smallest amount was observed in the fertilised variant with the introduction of CAM 32 (N_{30}) + H_2O and amounted to 46.5 t/ha. With an increase in the retail application of mineral fertilisers, a higher yield of

food potatoes was also established on the variant CAM 32 (N_{15}) + $MgSO_4$ + $Ca(NO_3)_2$ + H_2O – 48.5 t/ha.

CONCLUSIONS

Analysis of the obtained experimental material shows that the total number of nutrients involved in the cycle in different

fertiliser variants is different and is determined by the level of yield and affects the structure of the potato crop.

It was established that to ensure sustainable high-yield production on irrigated lands, rational and efficient use of fertilisers for table potatoes in the near future, it is recommended to use CAM 32 (N₁₅) + MgSO₄ + Ca(NO₃)₂ + H₂O to obtain a yield of table potatoes at the level of 48.5 t/ha and obtain a fractional composition at

the level of 55 g/plant with a tuber weight of 1,275.

Therefore, after the conducted research, it is recommended, in the conditions of the Forest-Steppe zone, when growing table potatoes, to ensure stable high-performance production against the background of irrigation, to use CAM 32 (N₁₅) + MgSO₄ + Ca(NO₃)₂ + H₂O. This will lead to a yield of 48.5 t/ha with a weight of tubers of more than 55g and not less than 1,275g.

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Лариса Олександрівна Семенко¹, Сергій Іванович Веремеєнко²,
Наталія Леонідівна Ющенко¹, Андрій Петрович Шатковський³

¹Національний університет біоресурсів та природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна

²Національний університет водного господарства та природокористування
33000, вул. Соборна, 11, м. Рівне, Україна

³Інститут водних проблем і меліорації НААН України
03022, вул. Васильківська, 37, м. Київ, Україна

Поєднання ефективного використання ірригації та мінерального живлення за вирощування картоплі столової

Анотація. Актуальність досліджень зумовлена зменшенням вологозабезпечення сільськогосподарських посівів в період вегетації внаслідок змін клімату та тенденцією до зменшення вологозабезпечення сільськогосподарських посівів. В той же час основним підходом по вирішенню цієї проблеми є поєднання фертигації зі зрошенням. Метою досліджень є встановлення залежності продуктивності картоплі столової за інтенсивної системи землеробства при застосуванні зрошення. На прикладі типового для регіону сільськогосподарського підприємства оцінено обсяги внесення азотних добрив для повного забезпечення культури в період вегетації. Для отримання наукових результатів було проведено аналітичний пошук та використанні польовий, лабораторний та статистичний метод обробки результатів. В результаті досліджень було оптимізовано розподіл нітрогену в порівнянні з втратами в поєднанні з фазами органогенезу. Для забезпечення зв'язку між рослиною, ґрунтом та добривами застосовували КАС 32 в дозах $N_{30}N_{15}$, що впливало на структурні показники врожаю картоплі. При застосуванні КАС 32 (N_{30}) + H_2O була отримана маса бульб на рівні $4,65 \text{ кг/м}^2$, і приріст врожаю становив $0,5 \text{ т/га}$. При застосуванні нітрогену з $MgSO_4$ приріст врожаю збільшувався до $1,5 \text{ т/га}$ в порівнянні з контролем. В процесі трансформації було встановлено, що застосування азотного живлення КАС 32 (N_{15}) + $MgSO_4$ + $Ca(NO_3)_2$ + H_2O за вирощування картоплі столової сприяло найінтенсивнішому формуванню маси бульб до $4,85 \text{ кг/м}^2$ порівняно з контролем – $4,6 \text{ кг/м}^2$. В кінцевій продукції спостерігалось збільшення фракції і становило більше 55 г/роsl . Аналіз врожайності свідчить про позитивну динаміку при застосуванні азотного живлення де приріст становив $2,5 \text{ т/га}$. Дані досліджені можуть бути застосованими сільськогосподарськими виробниками в зоні Лісостепу та Полісся для отримання високих приростів врожаїв при вирощуванні картоплі

Ключові слова: агресурсний потенціал, краплинне зрошення, поживні елементи, поживний режим ґрунтів

Kateryna Shemetun*, Anatolii Balaiev, Oksana Tonkha, Olena Pikovska

National University of Life and Environmental Sciences of Ukraine

03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

Microbiological assessment of sod-medium podzolic soil using various elements of biologisation

Abstract. To assess the ability of soils to self-repair and self-rehabilitation, it is important to monitor the indicators of soil microbiological activity. In conditions of manure deficiency, the restoration of organic matter of soils is provided by using non-commercial share of the crop and growing green manure crops, which is especially important for zonal soils of Ukrainian Polissia. The purpose of the study was to estimate the number of various physiological groups of microorganisms in sod-medium podzolic soil under the influence of various fertiliser systems. Field, laboratory, and statistical methods were used in the study. Field method: an experiment was conducted in a field of the Chernihiv Institute of Agricultural Microbiology and Agroindustrial Production of the NAAS with an area of sown plots of 102 m² on sod-medium podzolic light loamy soil with a humus content of 0.9-1.1% in 0-30 cm layer. The number of different groups of microorganisms that transform carbon and nitrogen compounds was determined in soil samples. Statistical methods – system analysis, mathematical and statistical analysis. Sowing of green manure such as lupine and oilseed radish had a positive effect on the number of ammonifiers (4.3-13.2 million CFU), which is 44-180% more than in the control. The mineral fertiliser system for potatoes also increased the number of ammonifiers by 15-50% compared to the option without fertilisers. The mineralisation-immobilisation coefficient was calculated as the ratio of the number of microorganisms that immobilise mineral forms of nitrogen to the number of organotrophs, and the pedotrophicity coefficient by the ratio of the number of microorganisms on soil agar to the number of microorganisms that grew on meat-peptone agar. It was established that the cultivation of green manure on sod-podzolic soil has a positive effect on the development of physiological groups of microorganisms and the microbiological processes tend to accumulate humus. The materials of the study are of practical value for agricultural producers who are engaged in growing potatoes on sod-podzolic soils in the possibility of replacing manure and mineral fertilisers in the fertiliser system of agricultural crops with green manure (lupine, oilseed radish)

Keywords: green manure, annual lupine, oilseed radish, physiological groups of microorganisms, pedotrophy coefficient

INTRODUCTION

Soil depletion occurs in conditions of intensive saturation of field crop rotations with agrocenoses that are demanding for fertility. Along with the phytomass of the crop, a significant amount of biophilic elements is permanently removed from the biological cycle. Unfortunately, fertilisation cannot fully compensate for these losses [1]. If earlier the microbiota to a certain extent eliminated the negative effect of the intensification of agricultural production, then in modern conditions there is a deterioration in both physical, chemical, and biological properties

of soils. As a result, the quantity and quality of organic matter decreases, and contamination with pollutants occurs, which leads to a decrease in the number of soil microbiota, which, in turn, reduces the stability of biocenoses and their degradation [2]. The microbiological state of soils is an indicator, on the one hand, of the disorders that occur in them, on the other – an indicator of the ability of soils to self-repair and rehabilitation.

In modern conditions, due to a significant decrease in the number of cattle, the availability of manure

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*Corresponding author

to replenish organic matter is limited. A possible way to obtain nutrients and restore soil fertility is to use straw and green manure [3; 4].

Studies by S.V. Skrypnichenko and G.V. Skyba [5] established that favourable conditions for the development of soil microbiota were formed under the influence of the combined application of straw and green manure in the sod-podzolic soil. The most pronounced effect was on the development of fungi and nitrifiers: their number was higher than the control and variants with separate use of straw and green manure.

Similar results were obtained in China and showed that inoculation of straw increases the rate of its decomposition and improves the biological properties of soils. Moreover, the intensity of straw decomposition is affected by its placement. Thus, the use of soil-free treatments increased the content of total soil organic carbon (TOC), microbial biomass carbon (MBC), fungi, actinomycetes and bacterial populations, and cellulose activity [6; 7].

On chernozem typical use of an organo-mineral fertiliser system with straw according to the previous studies reduced the overall biogenicity by 21-71% compared to the option without fertilisers, and by 23-78% – an organo-mineral fertiliser system with straw and green manure [8].

The development of bioenergy can lead to large-scale removal of grain straw from fields, which would have implications for soil organic carbon (SOC) and related properties. In 25 experiments lasting from 6 to 56 years, there was a tendency to increase the SOC content and total nitrogen content in the soil where straw was applied annually. However, the increase was significant in only six experiments and was <10% in most cases. The increase in microbial biomass C or N was always proportionally greater than for SOC or N. In the annual straw application simulation using the RothC model, a 90% increase in microbial biomass C over 100 years was achieved within 20 years, as biomass C moved to a new equilibrium value faster than the total SOC. The simulation also showed that if straw was removed within 50% of the years, the increase in SOC and C biomass was approximately 50% of what was applied annually. There is significant evidence that small changes in the total SOC have a disproportionately large impact on the physical properties of the soil, such as aggregate stability, water infiltration rate, and plough thrust, and that microbial activity is crucial for the formation of stable aggregates. Therefore, although changes in SOC by the addition or removal of straw are small, the removal of straw every year can lead to deterioration of the physical properties of the soil [9].

The use of vetch as green manure changed the structure of the bacterial community and affected functional groups that are associated with nutrient conversion, increased the number of bacteria involved in nitrogen fixation, nitrification, denitrification, methane oxidation, and sulphur reduction [10]. Sowing of oilseed

radish according to the organo-mineral fertiliser system, which included leaving straw in the amount of 1.2 t/ha of crop rotation area with nitrogen compensation N_{12} and application of mineral fertilisers $N_{78}P_{68}R_{68}$ caused an increase in the microbial transformation of organic matter by 64% compared to the non-sideration variant [8].

The use of red clover as a green manure led to the development of high microbial biomass and indicators of enzyme activity in the soil, and increased the yield of onions [11].

A long-term study for 47 years [12] showed a significant effect of green manure at a rate of 4 t C ha⁻¹ on the composition and function of soil microbial grouping, bacterial and fungal biomass, and total microbial biomass, but not arbuscular mycorrhiza (AM) fungi. The introduction of sawdust contributed to a greater development of fungal biomass. Protease and arylsulfatase activity were lower when using green manure compared to the mineral fertiliser variant, while acid phosphatase activity increased. It can be concluded that green manure had a beneficial effect on the microbial properties of the soil, but in some aspects, it differed from other organic materials (manure and sawdust), which could be explained by differences in their composition.

Studies have shown that legume green manure can improve the composition of microbial biomass and the content of organic matter in the soil [13; 14].

Study of the effect of green manure fertilisers of leguminous crops (*Vigna radiata*, *Vigna unguiculata*, *Glycine max*, *Cajanus cajan*, *Cyamopsis tetragonoloba*) and nitrogen fertilisers for microbial biomass of the soil for the cultivation of rice (*Oryza sativa*) and wheat (*Triticum aestivum*) increased the total microbial biomass by 1.79 times, bacterial biota – by 3.36, and fungi – by 1.46 times. The use of nitrogen fertilisers in comparison with the control increased the indicators by 1.40, 1.17, and 1.29 times, respectively. Therefore, biological indicators are highly sensitive to the beneficial effects of legume green manure in the rice-wheat system and can be used as an indicator of soil quality [15].

The authors explain the increase in the rate of mineralisation of C and N by sideration of leguminous crops due to the intake of “fresh” organic matter, in particular, organic N [15; 16], which affects the biological activity of the soil and subsequently the availability of N and C [8; 16; 17]. Studies [18] found a 205% increase in the accumulation-mineralisation coefficient (K_a-m) with the use of leguminous green manure compared to the control.

Studies conducted in China concluded that the use of inorganic nitrogen increased soil nitrification, while green manure reduced it, which is consistent with changes in the concentration of nitrates in the soil. These results indicate that the use of winter green manure is an effective practice for improving nitrogen management [18].

Soil microorganisms play an important role in maintaining the biogeochemical cycle of nitrogen for thousands of years, including due to their biological

nitrogen fixation [19]. What is important is that plants cannot fully utilise the forms of nitrogen available to them. After all, mobile soil nitrogen compounds can be lost under the influence of both biotic and abiotic factors, as a result of which nitrogen reserves are even more depleted.

The purpose of the study was to estimate the number of different physiological groups of microorganisms in sod-medium podzolic soil using various elements of biologisation.

MATERIALS AND METHODS

The study was conducted in 2016-2019 in a long-term field trials of the Chernihiv Institute of Agricultural Microbiology and Agroindustrial Production of the NAAS in crop rotation with subsequent alternation of agricultural crops:

1. Winter wheat;
2. Corn;
3. Barley with Clover sowing;
4. Clover;
5. Winter rye;
6. Potatoes;
7. Oat;
8. Lupin.

The system of tillage in crop rotation was generally accepted for the Polissia zone of Ukraine: the main shelf tillage was carried out to a depth of 25-27 cm and it included stubble peeling after harvesting winter rye, cultivation, and ploughing. The area of sown plots in the field experiment was 102 m². The soil of the experimental site was sod-medium podzolic light loamy on glacial water deposits. The content of humus in the arable layer was 0.99-1.1%, the content of mobile phosphorus compounds according to Kirsanov [20] – 29.5-31.7, exchange potassium according to Maslova [21] – 10.8-13.9 mg/100 g of soil, pH – 5.0-5.5.

Soil samples were taken from layers of 0-10, 10-20, 20-30, and 30-50 cm of soil with a cane drill according to the DSTU ISO 10381-6-2001 [22] in the 3rd ten days of May. Samples were taken from five points in stationary experiments using the “envelope” method at the experimental

site. Preparation of soil samples for the study of aerobic microbiota in laboratory conditions was carried out in accordance with DSTU ISO 10381-6-2001 [22]. Determination of the number of different groups of soil microorganisms was carried out by sowing soil suspension on solid nutrient media according to DSTU ISO 7847:2015 [23]. The total number of microorganisms that decompose organic compounds containing nitrogen was studied on meat-peptone agar (MPA). Microorganisms that assimilate mineral forms of nitrogen were studied on a starch-ammonia medium (SAA). The number of microorganisms that synthesise melanins – on Chapek medium at PH=5.0, decomposing humates – on medium with sodium humate, pedotrophs – on soil agar.

The mineralisation-immobilisation coefficient (K_{m-i}) was calculated by the equation (1):

$$K_{m-i} = \frac{C_{SAA}}{C_{MPA}}, \quad (1)$$

where C_{SAA} – the number of microorganisms that developed on a starch-ammonia medium; C_{MPA} – the number of microorganisms on meat-peptone agar.

The pedotrophic coefficient (K_{ped}) was calculated by the equation (2):

$$K_{ped} = \frac{C_{SA}}{C_{MPA}}, \quad (2)$$

where CSA – the number of microorganisms on the soil agar; $CMPA$ – the number of microorganisms grown on meat-peptone agar.

The organic matter transformation index (K_{tor}) was calculated according to B. Mukha [24], equation (3):

$$K_{tor} = (C_{MPA} + C_{SAA}) \cdot \frac{C_{MPA}}{C_{SAA}} \quad (3)$$

Statistical data processing was performed using the Statistica software suite.

RESULTS AND DISCUSSION

Table 1 shows the number of different groups of microorganisms in sod-medium podzolic soil with different fertiliser options.

Table 1. The number of the main physiological groups of microorganisms in sod-medium podzolic soil under various fertiliser options, million tonnes. CFU in 1 g of absolutely dry soil

Fertiliser variant	Soil layer, cm	Ammonifying	Amylolytic	Pedotrophic	Humate-decomposing ¹	Micromicetes ¹
Without fertilisers (control)	0-10	3.8 ± 0.39	7.9 ± 0.39	0.42 ± 0.059	126.4 ± 28.52	3.3 ± 0.07
	10-20	4.2 ± 0.43	8.8 ± 0.41	0.45 ± 0.063	110.4 ± 22.35	3.5 ± 0.08
	20-30	4.7 ± 0.45	9.2 ± 0.53	0.49 ± 0.069	95.2 ± 19.21	3.8 ± 0.10
	30-50	6.2 ± 0.56	11.6 ± 0.59	0.55 ± 0.063	59.3 ± 4.08	4.6 ± 0.15
Green manure 1 – annual lupine	0-10	5.5 ± 0.22	3.8 ± 0.22	0.57 ± 0.009	96.4 ± 8.78	4.8 ± 0.15
	10-20	6.4 ± 0.30	4.5 ± 0.26	0.68 ± 0.073	65.3 ± 6.91	4.5 ± 0.16
	20-30	9.5 ± 0.56	5.2 ± 0.30	0.65 ± 0.063	55.2 ± 6.31	8.2 ± 0.29
	30-50	6.1 ± 0.49	7.4 ± 0.49	0.48 ± 0.075	38.9 ± 2.76	7.1 ± 0.26
N ₁₂₀ P ₉₀ K ₁₂₀	0-10	5.7 ± 0.48	7.8 ± 0.46	0.65 ± 0.063	89.4 ± 9.3	4.2 ± 0.07
	10-20	6.9 ± 0.31	7.8 ± 0.47	0.93 ± 0.075	94.1 ± 3.59	5.2 ± 0.42
	20-30	5.4 ± 0.61	7.9 ± 0.48	0.90 ± 0.072	96.4 ± 8.78	5.4 ± 0.08
	30-50	5.1 ± 0.39	8.8 ± 0.61	0.50 ± 0.069	65.4 ± 6.92	3.2 ± 0.36

Table 1, Continued

Fertiliser variant	Soil layer, cm	Ammonifying	Amylolytic	Pedotrophic	Humate-decomposing ¹	Micromycetes ¹
Green manure 2 – oilseed radish	0-10	5.8 ± 0.48	6.4 ± 0.51	0.63 ± 0.003	49.9 ± 2.14	4.2 ± 0.08
	10-20	8.2 ± 0.79	6.6 ± 0.57	0.84 ± 0.081	39.3 ± 2.86	8.4 ± 0.34
	20-30	13.2 ± 0.41	7.0 ± 0.57	0.79 ± 0.055	37.2 ± 4.63	9.2 ± 1.71
	30-50	4.3 ± 0.13	7.3 ± 0.89	0.44 ± 0.045	95.2 ± 2.09	4.1 ± 0.36

Note: ¹thous. CFU/g of soil

In the soil layer of 30-50 cm, a decrease in the proteolytic activity of microorganisms was observed: where the greatest number of amylolytic and humate-decomposing bacteria was noted (11.6 ± 0.59), which was 54% more compared to the variant with annual lupine siderate, 31.8% compared to variant $N_{120}P_{90}K_{120}$, and by 58.9% compared to the option with oilseed radish.

Sowing of green manure (lupine and oilseed radish) had a positive effect on the number of ammonifiers (4.3-13.2 million CFUs), which is 44-180% more than the control. The mineral fertiliser system for potatoes also increased the number of ammonifiers by 15-50% compared to the non-fertiliser option, with the exception of the 30-50 cm layer, where the indicators were higher in the control. There were changes in the number of ammonifiers with soil depth from 3.8 ± 0.39 to 6.2 ± 0.56 million CFUs in 1 g of absolutely dry soil. Volkogon *et al.* [25] found that the variants using only mineral fertilisers showed an increase in the pool of mineral nitrogen immobilisers against the background of a small amount of ammonifiers, which indicates an increase in the mineralisation of microbial cenosis: the mineralisation-immobilisation coefficients in the flowering phase increased from 1.86 for the introduction of $N_{40}P_{40}K_{40}$ up to 2.42 per fertiliser $N_{120}P_{120}K_{120}$. At the same time, the effect of straw and green manure on the application of mineral fertilisers provided a reduction in the negative consequences of the intensification of mineral fertilisation of potatoes. Under these conditions, the mineralisation-immobilisation coefficient was 1.20 at the norm of $N_{40}P_{40}K_{40}$ and 1.23 with the introduction of $N_{120}P_{120}K_{120}$.

In the variants with green manure, the highest content of this group of microorganisms was in a layer of 20-30 cm and was 9.5 ± 0.56 , respectively, in the variant with lupine and 13.2 ± 0.41 million CFUs in 1 g of absolutely dry soil with oilseed radish. This redistribution is explained by the embedding of the bulk of green fertiliser in this layer. Under the mineral fertiliser system, the content of ammonifying microorganisms did not change much in the soil layers and amounted to 5.1 ± 0.39 - 6.9 ± 0.31 million CFUs in 1 g of absolutely dry soil.

The largest number of humate-decomposing microorganisms, which according to the studies by

G.O. Iutyńska [26] take part in the decomposition of the nuclear part of humus substances, was obtained on the variant without fertilisers and amounted to 126.4 ± 28.52 in the 0-10 cm layer and 59.3 ± 4.08 in the 30-50 cm soil layer. In the variant with lupine green manure, the content of this group of microorganisms was 96.4 ± 8.78 in a 0-10 cm layer and amounted to 38.9 ± 2.76 million CFUs in 1 g of absolutely dry soil in a 30-50 cm layer. Consequently, the content of humate-decomposing microorganisms with depth decreased on variants with green manure, which indicates a slowdown in the decomposition of organic matter in the soil with depth and creates prerequisites for an increase in humus reserves, which is especially important for poor sod-podzolic soils.

According to the mineral fertiliser system $N_{120}P_{90}K_{120}$, the content of this group of microorganisms was high and amounted to 65.4 ± 8.78 – 96.4 ± 8.78 million tonnes. CFU in 1 g of absolutely dry soil, which indicates an accelerated decomposition of organic matter in soils, which is especially dangerous for sod-podzolic soils.

The opposite relationship was obtained by the number of micromycetes involved in the synthesis of humus substances. Thus, it is advisable to consider green manure crops of oilseed radish and lupine by the number of the above-mentioned bacteria (the largest number of micromycetes and the smallest – humate-decomposing) as a source of organic matter recovery. Compared to the control, the number of microorganisms was 1.8-2.5 times higher depending on the soil layer.

Changes in the structure and functioning of microbial cenosis of soils occur under the influence of its involvement in agro-industrial production. O.S. Demyanyuk *et al.* [27] found that on low-fertile soils, such as sod-podzolic and grey forest without fertilisation, the impact of agricultural activities on the soil microbiota was greater compared to chernozems, which led to a decrease in the total number of microorganisms by 2.2-4.5 times. This fact is also confirmed by the results of the conducted studies, namely a large number of humate-decomposing and amylolytic and the smallest pedotrophic microorganisms and micromycetes for growing table potatoes.

Table 2 shows the coefficients of soil microbiological processes under different fertiliser options.

Table 2. Orientation of microbiological processes in sod-medium podzolic soil under various fertiliser options

Fertiliser variant	Soil layer, cm	K_{ped}	K_{m-i}	K_{accum}
Without fertilisers (control)	0-10	0.11	2.1	0.38
	10-20	0.11	2.1	0.42
	20-30	0.10	2.0	0.47
	30-50	0.09	1.9	0.62
Green manure 1 – annual lupine	0-10	0.10	0.7	0.15
	10-20	0.11	0.7	0.44
	20-30	0.07	0.5	0.85
	30-50	0.08	1.2	0.61
$N_{120}P_{90}K_{120}$	0-10	0.11	1.4	0.37
	10-20	0.13	1.1	0.39
	20-30	0.17	1.5	0.44
	30-50	0.10	1.7	0.41
Green manure 2 – oilseed radish	0-10	0.11	1.1	0.58
	10-20	0.10	0.8	0.82
	20-30	0.06	0.5	1.34
	30-50	0.10	1.7	0.23

V.P. Patyka *et al.* [28] recommend assessing the ecological state of agricultural soils and establishing the microbiological processes in soils, determining the coefficients of pedotrophy, oligotrophy, and the coefficient of mineralisation-immobilisation. The pedotrophic coefficient indicates the functionality of the soil microcenosis structure and indicates the degree of organic matter development. K_{ped} on all variants was low and amounted to 0.06-0.13. At the control, it did not change much for the layers of sod-podzolic soil and amounted to 0.09-0.11. Options with green manure practically did not differ in this coefficient: for growing lupine, K_{ped} was 0.08-0.11, and oilseed radish – 0.06-0.11. According to the mineral fertiliser system, the highest value of the pedotrophy coefficient was set in a layer of 20-30 cm – 0.17.

Study by V.P. Patyka *et al.* [28] found that the coefficients of pedotrophy in agricultural land soils were lower and amounted to 0-0.177 compared to soils of natural cenoses ($K_{ped} = 0.739-963$). The researchers note an increase in the intensity of decomposition of organic matter in the soil and natural ecosystems, in particular, humus compounds. As a result of our research, it was also established that with intensive agricultural use, namely the cultivation of table potatoes on sod-podzolic soil, a low degree of organic matter development was noted in all variants of the experiment.

The coefficient of organic matter accumulation characterises the intensity of accumulation of these compounds in the soil. The highest accumulation rates were observed in a layer of 20-30 cm for all fertiliser options, which is probably conditioned by the use of shelf tillage, in which the largest amount of earned organic substances of green manure crops and plant residues enter soil layer.

At the control, the accumulation coefficient gradually increased with depth and amounted to 0.38, 0.42, 0.47, and 0.62 in soil layers of 0-10, 10-20, 20-30, and 30-50 cm, respectively. Close to the control for the value of this coefficient was the option of mineral fertiliser for table potatoes $N_{120}P_{90}K_{120}$ and was 0.37; 0.39; 0.44, and 0.41, respectively, for layers of sod-podzolic soil.

Growing green manure increases the accumulation of organic matter in the soil and K_{accum} in the 0-30 cm layer, it was 0.85 on the variant with lupine and 1.34 on the variant with oilseed radish, lower values were set on the control – 0.47, and on the mineral fertiliser system – 0.44.

In the variant with green manure, it is necessary to pay attention to the additional application of nitrogen, since there is an accumulation of organic matter in the soil and the mineralisation-immobilisation coefficient in a layer of 20-30 cm is $K_{m-i} = 0.5$, which is 2 times less than the optimal (1.0). In particular, the intensity of mineralisation-immobilisation processes was highest in the variant without fertilisers, where this coefficient was 1.9-2.1. According to the mineral fertiliser system, this indicator in a layer of 10-20 cm approached the optimal one and amounted to 1.1.

Thus, on sod-podzolic soil, the cultivation of green manure has a positive effect on the development of physiological groups of microorganisms and the microbiological processes tend to accumulate humus. Similar conclusions are drawn by O.Yu. Kolodyazhnyy and M.V. Patyka [29] that the use of an ecological system of agriculture with differentiated tillage positively affected the microbiological processes for growing winter wheat and contributed to the accumulation of organic matter and mineral nitrogen in the soil, and increased the number

of different groups of microorganisms: ammonifying bacteria – up to 4.63, spore-forming – up to 0.65, actinomycetes – up to 0.87 million CFUs/g of absolutely dry soil.

CONCLUSIONS

Table potato fertiliser systems had an impact both on the number of individual groups of microorganisms and on the microbiological processes in sod-podzolic light loamy soil, which were estimated by pedotrophic coefficients (K_{ped}), mineralisation-immobilisation (K_{i-m}) and accumulation of organic matter (K_{accum}).

It was established that growing table potatoes without fertilisation (control) leads to accelerated mineralisation of organic matter of the soil and contributes to the intensity of transformation processes of nitrogen compounds in sod-medium podzolic light loamy soil. This variant provided the largest number of humate-decomposing microorganisms, the smallest number of

micromycetes, and the mineralisation-immobilisation coefficient 2 times more than the optimal. Similar values were obtained on the mineral fertiliser variant $N_{120}P_{90}K_{120}$.

Cultivation of lupine and oilseed radish increased the number of ammonifiers by 44-180% compared to the control, and there was a tendency to humus accumulation. According to the pedotrophic coefficient, a low degree of development of soil organic matter was established in all variants of the experiment, its values were 0.06-0.13 and did not depend much on the fertiliser option.

According to the content of various groups of microorganisms and the coefficients of pedotrophy, mineralisation-immobilisation, and accumulation, a positive effect of sideration on the processes of humus formation was established. In further study, it is planned to investigate the effect of combining the cultivation of green manure against the background of full mineral fertiliser on the biological activity of the soil.

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Катерина Ігорівна Шеметун, Анатолій Джалілович Балаєв, Оксана Леонідівна Тонха, Олена Володимирівна Піковська

Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна

Мікробіологічна оцінка дерново-середньопідзолистого ґрунту за застосування різних елементів біологізації

Анотація. Для оцінки здатності ґрунтів до самовідновлення і самореабілітації важливо проводити моніторинг показників мікробіологічної активності ґрунтів. В умовах дефіциту гною відновлення органічної речовини ґрунтів забезпечується шляхом використання нетоварної частки врожаю та вирощуванням сидеральних культур, що особливо актуально для зональних ґрунтів Полісся України. Метою досліджень була оцінка чисельності різних фізіологічних груп мікроорганізмів у дерново-середньопідзолистому ґрунті під впливом різних систем удобрення. У роботі були використані польові, лабораторні і статистичні методи. Польовий метод: дослідження проводили у стаціонарному досліді Чернігівського інституту АПВ НААН із площею посівних ділянок 102 м² на дерново-середньопідзолистому легкосуглинковому ґрунті із вмістом гумусу 0,9–1,1 % в шарі 0–30 см. У зразках ґрунту визначали чисельність різних груп мікроорганізмів, що трансформують сполуки карбону та нітрогену. Статистичні методи – системний аналіз і математико-статистичний. Посів таких сидератів, як люпин і редька олійна позитивно вплинув на чисельність амоніфікаторів (4,3–13,2 млн. КУО), що більше на 44–180 % порівняно з контролем. Мінеральна система удобрення картоплі також збільшила чисельність амоніфікаторів на 15–50 % порівняно з варіантом без добрив. Коефіцієнт мінералізації–імобілізації розраховували як відношення чисельності мікроорганізмів, що імобілізують мінеральні форми нітрогену до кількості органотрофів, а коефіцієнт педотрофності за відношенням чисельності мікроорганізмів на ґрунтовому агарі до чисельності мікроорганізмів, що виростили на м'ясопептонному агарі. Встановлено, що на дерново-підзолистому ґрунті вирощування сидератів позитивно впливає на розвиток фізіологічних груп мікроорганізмів і спрямованість мікробіологічних процесів має тенденцію щодо накопичення гумусу. Матеріали статті складають практичну цінність для виробників сільськогосподарської продукції, які займаються вирощуванням картоплі на дерново-підзолистих ґрунтах у можливості заміни гною і мінеральних добрив у системі удобрення сільськогосподарської культури на сидерати (люпин, редька олійна)

Ключові слова: сидерат, люпин однорічний, редька олійна, фізіологічні групи мікроорганізмів, коефіцієнт педотрофності

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E-mail: info@agriculturalscience.com.ua

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