INFLUENCE OF SIDERATES ON THE AGRO-ECOLOGICAL CONDITION OF THE SOIL

Oleksandr Tkachuk[1]
Oleksiy Alieksieiev[2]

DOI: https://doi.org/10.30525/978-9934-26-290-6-9

Abstract. The work is devoted to the study of the expediency of using siderates for indicators of the agro-ecological state of the soil in the conditions of modern intensive crop rotation. Fertility indicators and soil contamination with heavy metals were studied. Correlation-regression dependencies between the studied factors were established and calculated. *The purpose.* Study of the siderates on the agro-ecological condition of the soil. *Result*. It was established that the biological mass of siderates, worked into the soil, helps to increase the content of humus by 0.11-0.14%, alkaline hydrolyzed nitrogen – by 1.7-7.1%, exchangeable potassium – by 27.4-32.2%. The highest content of humus in the soil is provided by siderates of peas and winter rapeseed – 2.44% each, alkaline hydrolyzed nitrogen – 127 mg/kg – peas, mobile phosphorus – 520 mg/kg – winter wheat, exchangeable potassium – 230 mg/kg – winter rapeseed, the largest amount of absorbed bases – 16.8 mg-eq./100 g – peas, the lowest hydrolytic acidity – 1.60 mg-eq./100 g – winter wheat, the highest pH value 5.85 – spring barley. *Value/originality.* It was determined that the cultivation of siderates leads to an increase in the content of mobile heavy metals in the soil by 17.2-24.3%, cadmium – by 10.0-14.3%, copper – by 17.6-22.2%, zinc – by 34.7-39.9%, compared to the version without siderates. Among the studied siderates, the lowest content of lead in the soil – 1.28 mg/kg and cadmium – 0.20 mg/kg is provided by winter rapeseed; copper – 0.51 mg/kg – peas and winter rapeseed; zinc – 1.73 mg/kg – spring barley.

[1] Doctor of Agricultural Sciences, Associate Professor,
Vinnytsia National Agrarian University, Ukraine
[2] Candidate of Agricultural Sciences, Associate Professor,
Vinnytsia National Agrarian University, Ukraine

1. Introduction

Soil, as a natural resource, is constantly subject to natural and anthropogenic influences. The influence of natural factors occurs continuously, but mineral and organic substances are in balance, thanks to which the natural course of geological processes is not disturbed.

Anthropogenic influence on soils causes their degradation, leads to a decrease in the productivity of agricultural lands. In Ukraine, the ecological consequences of soil degradation and deterioration of their quality have become particularly acute in the modern period due to the use of land as the only means of subsistence in conditions of survival at the expense of natural soil fertility, without compensation for its costs. High productivity of land in this case is ensured by applying high rates of mineral fertilizers and pesticides.

This leads to a merciless depletion of the natural fertility of soils, which is called degradation. Soil degradation leads to the deterioration of soil properties, fertility and quality, its contamination with chemical toxic substances, which is caused by a change in the conditions of soil formation due to the influence of natural or anthropogenic factors. Degradation of soils, and often their complete exclusion from agricultural use, occurs as a result of the processes of water and wind erosion, dehumification, decalcification, over-compaction by agricultural machinery, irrational operation of irrigation systems, which leads to flooding and waterlogging, secondary salinization and salinization of soils; due to violations of agricultural technology, overgrowth with weeds and shrubs, unbalanced application of mineral fertilizers, pollution with toxic substances, radionuclides, unregulated livestock grazing, etc.

As a result of such anthropogenic intervention, soils lose their natural stability, which leads not only to a decrease in their productivity, but also to a complete loss of soils and their removal from cultivation. The consequence of this can be not only a decrease in the productivity of crops, but also a significant deterioration in the quality of the grown products, which not only reduces their nutrition, but also accumulates toxic substances: heavy metals, pesticides, radionuclides, salts and acids, oil products.

The degree of soil resistance to chemical pollution is characterized by such indicators as the humus composition of the soil, acid-base properties, oxidation-reduction properties, cation-exchange properties, biological activity, the level of groundwater, the proportion of substances in a dissolved state, etc.

A situation has arisen where the intensive use of heavy machinery in soil cultivation, the application of pesticides and mineral fertilizers, and chemical preparations violate the natural laws of evolution. Self-regulation in living nature was broken, which weakened the self-defense of plants, animals, and humans.

For a long time, the application of organic fertilizers in the form of manure was a factor in restoring and stabilizing the agro-ecological condition of soils, and therefore a factor in improving the quality of products grown on them. In modern conditions, due to the lack of animal husbandry, it is impossible to solve this problem by adding manure. Therefore, one of the most important ways to restore such soils can be the maximum return to the soil of the plant mass of crops that are not used for economic production and their waste. Such substances can be siderates, as well as by-products of crop production in the form of stubble, straw, stalks, tops, etc. The question of the influence of these organic substances on the productivity of crops of the following crops in crop rotation has been studied at a sufficient level by Artemenko V. (2003), Berdnikov O.M. (2004), Makarova G.A. (2008), Gospodarenko H.M. (2012–2016), Razanov S.F. (2020), Pantsyreva H.V. (2020) and others.

At the same time, the change in indicators of the agro-ecological state of the soil, in particular the content of nutrients, acidity, heavy metals and other toxicants in it, as well as the influence of siderates and plant waste on the quality and ecological safety of the grown products, has not been studied enough, which determines the relevance of the chosen topic.

2. Analysis of recent research and publications

The relevance and significance of the problem of reproduction of soil fertility in agricultural production is due to the sharp contradiction between the need to ensure sustainable development of the agricultural sector of the economy and the intensive development of soil degradation processes that make it impossible to sustainably reproduce soil fertility. The main reason for this situation is the dominance of an unbalanced deficit system of agriculture in Ukraine, due to which the most fertile chernozems in the world have turned into soils with an average level of fertility and continue to deteriorate, and the harvests of recent years are mostly the result of a decrease in natural fertility and the impoverishment of its potential part [1–3].

In the agriculture of Ukraine, 79% of profit is obtained due to natural fertility and only 21% is the result of the introduction of technologies. At the same time, there is an "ecological eating away" of profit, since the losses from the decrease in soil fertility are close to, and in some years higher than, the profit from the sale of products by agricultural enterprises of Ukraine. Thus, in 2010, from 18.5 million hectares of arable land, on which the main groups of crops were grown, 2.38 million tons of nitrogen, phosphorus, and potassium were irretrievably lost, amounting to more than UAH 16.3 billion. However, this is only the cost of fertilizers, and the costs of their application are not taken into account. According to other data, the annual economic costs from the shortage of products due to soil erosion in Ukraine in general are estimated at 1.5 billion US dollars, and together with the incurred costs – about 2 billion dollars [4; 5].

In order to stop these negative processes, it is necessary to make wider use of natural ways of restoring and replenishing the reserves of organic matter in the soil, thanks to which not only the degradation processes in the soil will stop, but also the yield of plants grown on them will increase and the costs of their cultivation will decrease. In conditions of shortage of organic fertilizers in the form of manure, emphasis should be placed on green fertilizers – siderates [6; 23].

Green fertilizers (siderates) are fresh plant mass of specially grown crops, partially or completely worked into the soil to increase its fertility and improve the nutrition of subsequent plants with nitrogen and other elements. These cultures are called siderates, and the practice itself is called sideration, green manure is understood as the application of not yet dead green juicy biomass of plants, rich in sugars, starch, protein and nitrogen, to the soil, as well as their roots, which were still functioning at the time of tillage. This fundamentally distinguishes green manure from the application of other organic fertilizers to the soil, both dry (straw) and partially decomposed (manure) [7–10].

The production of siderates, like any other organic fertilizers, enriches the soil with organic substances, reduces its acidity, weediness of fields, increases buffering, improves the structure of the soil, and activates the vital activity of soil microorganisms. Their cultivation prevents the loss of nutrients due to erosion and migration along the soil profile. Sideration is used in fields far from farms, where it is economically unprofitable to bring manure, as well as in farms with small production of organic fertilizers, in specialized farms without animal husbandry. Green fertilizers are of great importance during the reclamation of produced quarries of non-metallic minerals and contaminated soils. For example, clover grows well on areas contaminated with motor oils. To detoxify the soil, trefoil, burgun and sweet clover are sown [18–21; 37].

The organic substance of green fertilizer can be considered as a reserve of all nutrients necessary for plants, which are created in the soil and which are not immediately transformed into an assimilated form, but gradually, throughout the growing season, ensuring continuous growth and development of plants. Especially valuable is green manure from leguminous crops, capable of enriching the soil with nitrogen by fixing it from the atmosphere with nodule bacteria. In this sense, the planting of leguminous green-fertilized plants can be called a living factory of nitrogen fertilizers, which without complex machines, but only thanks to the work of nitrogen-fixing microorganisms, bind a large amount of free nitrogen in the air into a useful form of soil organic matter. So, when 10 tons of green mass of lupine is harvested, the soil is enriched with nitrogen by 54-56 kg/ha, clover – by 62, peas and fodder beans – by 52, and cornflower – by 59 kg/ha. It is also important that the soil fertilized with nitrogen accumulated by leguminous plants does not require additional costs [22–25].

Siderates mobilize nutrients from the lower layers of the soil and move them into the arable layer. If the application of manure is the return to the soil of nutrients that were used by plants to create a crop, then the use of green manure is the mobilization of nutrients from solar energy, the atmosphere, and the lower layers of the soil, which are not used much [26; 27].

Green fertilizers help restore the normal cycle of organic matter and nitrogen in the soil. The results of research using labeled isotopes showed that when white mustard is used in the form of a harvest siderate, the nitrogen nutrition of barley plants and winter grain crops improved significantly, mainly due to an increase in the nitrogen utilization rate of mineral fertilizers by 40-60%. Increasing the resources of additional forms of nitrogen not only creates more favorable conditions for the growth and development of agricultural crops, but also reduces the contamination of the soil and plant products with nitrates and other harmful substances that can come with mineral fertilizers [28–32].

The diversity and specificity of sidereal crops requires theoretical and technological substantiation of their cultivation and fertilization in order to reduce the anthropogenic load on the surrounding natural environment, increase the productivity of crop rotations with the reproduction of the organic component of soils [37; 38].

Depending on the amount of heat, precipitation, local conditions, the granulometric composition of the soil, the presence of fertilizers and seeds, the following crops can be sown on siderates: legumes – perennial and annual lupins, white and yellow burdock, seradella, winter vetch and mountain vetch, diaper, peas, etc.; cereals – winter rye, wheat, barley, ryegrass, as well as sown cereal and leguminous perennial grasses, using the first cut for cattle feed, and the fallow – for fertilizer. In the presence of nitrogen fertilizers, it is promising to use cabbage crops (winter and spring rapeseed, winter and spring turnip, oil radish, white mustard, perko), phacelia, fodder peas and other fast-growing crops and their mixtures for sideration. Astragalus, mung bean, quinoa, fenugreek, alfalfa, asparagus, lentils, horse beans, gorse, sabdar, bers, soybean, rye, paiza, Sudan grass and many others can be used as side crops [39–43].

The rapid dynamics of the climate in the direction of warming significantly changes the usual ideas about the diversity of the biological set and the technological capabilities of some long-known cultures. Previously well-known cultures can manifest themselves under these conditions from previously unknown sides and demonstrate excellent productivity. It is advisable to test new crops that tolerate dry periods well, are undemanding to the soil, and are adapted to growing in deserts. These are plants from the leguminous family (woolly astragalus; naked, rough and Ural licorice; small-hairy, mouse and thin-leaved peas; tuberous and meadow plantain; Don and large safflower; large-flowered fenugreek; false or ordinary camel thorn), slender-legged (Karelina reed, multi-stemmed hairy and giant sedge, sedge and Colchis) and many other cultures. The main thing is that the soil is not empty, but is covered with green cover [44].

The soil and climatic conditions of Ukraine make it possible to sow a large number of crops on green manure. In regions with sufficient moisture, lupine, clover, vetch-oat mixtures, ryegrass, cabbage crops should be sown; in more arid conditions – vetch-rye, vetch-oat and pea-oat mixtures, peas, burdock, asparagus [24].

Seradella, lupine and phacelia, which are very demanding on moisture, grow well on poor sandy soils. Only white lupine and burkun tolerate carbonate soils well. Thin-legged – winter rye and its varieties (green-eared, perennial), oats, ryegrass are suitable for poor soils with excessive acidity. Cabbages need more compact and fertile soils (except for the relatively undemanding oil radish) [35].

In the first year of operation, the nitrogen utilization rate of green manure is usually higher than that of manure. In addition, leguminous siderates have a well-developed root system that penetrates deep into the soil, so they absorb nutrients from the lower layers of the soil, as well as phosphorus and other nutrients from poorly soluble compounds. In this regard, during the decomposition of the earned plant mass, the upper layer of the soil is enriched not only with organic substances and mobile nitrogen compounds, but also with phosphorus, potassium, calcium and other elements [13].

In terms of the degree of influence on crop yield, siderates are close to litter manure at the rate of 20-30 t/ha, and the costs of their production and application are 2-4 times lower [10].

Therefore, sideration, in addition to replenishing the content of organic substances and nitrogen in the soil, has such a versatile positive effect on the soil: the acidity of the soil is slightly reduced, the mobility of aluminum is reduced, and the buffering capacity and absorption capacity of cations is increased; soil erosion and degradation is eliminated; soil microbiological processes are regulated as a result of stimulation of the reproduction of microorganisms; the structure improves, the volumetric mass and density of the soil decrease; the water permeability and moisture capacity of the soil increases significantly; plant diseases are reduced; soil nutrients are mobilized; weediness of the fields decreases; the efficiency of fertilizers and liming increases.

In most literary sources, it is noted about the positive impact of growing siderates on the condition of the soil mainly in generalized phrases, without clear data on the improvement of certain indicators.

In particular, it is known that siderates replenish humus reserves in the surface layer of the soil, thus increasing the fertility of the arable horizon, enriching it with nitrogen, phosphorus, potassium and other macro- and microelements useful for cultivated plants. It has also been established that green fertilizers reduce soil acidity.

At the same time, the issue of reducing soil pollution with toxic elements remains relevant: heavy metals, pesticide residues, radionuclides, salts and acids, which, especially today, have increased their danger not only in relation to soils, but also to accumulation in plant products.

The agrosphere of Ukraine is characterized by intensive agriculture due to favorable conditions for the production of plant products, one of which is a large amount of chernozem compared to other countries of the world. Intensive farming on these soils leads to removal of biogenic elements with the harvest, which reduces the amount of humus and their fertility. Under such conditions, there is a need for their constant renewal, which increases the volume of use of mineral fertilizers. In the conditions of intensive agriculture, about 130 million tons of fertilizers are used annually, including 70 million tons of nitrogen, 39 million tons of phosphorus, and 26 million tons of potassium fertilizers [17; 46].

The use of high doses of mineral fertilizers along with the renewal of soils with nitrogen, potassium, phosphorus and other nutrients increases various toxicants in them, particularly heavy metals. It is known that with each kg of ammonium nitrate, 0.5 mg of lead and 0.05 mg of cadmium enters the soil, with double superphosphate 4.4 mg of lead and 0.05 mg of cadmium, and with potassium chloride 3.0 mg lead and 3.0 mg of cadmium [19; 40].

Analyzing the safety of food products in Ukraine in recent years, it was found that they exceeded the hygienic standards regarding the content of lead, cadmium and mercury. It was established that about 10% of food samples contain salts of heavy metals, half of which exceed the MPC [36; 45].

3. Conditions and methods of research

The research was intended to study the influence of siderates, which spontaneously sprouted after the loss of crop yields and disking of the field, on indicators of fertility and agro-ecological condition of soils.

The following observations, records and measurements were carried out: the determination of soil pollution by mobile forms of heavy metals, soil fertility indicators was carried out in the certified and accredited laboratory of the Zhytomyr branch of the State Institution "State Soil

Protection" of the Ministry of Agrarian Policy and Food of Ukraine. Soil samples were taken from the 0–20 cm layer in accordance with DSTU ISO 10381-1:2004 [1; 7; 30–33]; determination of the content of humus in the soil – according to the Tyurin method in accordance with DSTU 4289:2004 [10–13; 22–24]; determination of the content of mobile forms (after extraction with an acetate-ammonium buffer solution pH 4.8) of heavy metals in the soil: lead, cadmium, copper and zinc – by the method of atomic absorption spectrophotometry in accordance with DSTU 4362:2004, DSTU 4770 (2, 3, 9): 2007 [14–18]; determination of the reaction of soil pH saline – ionometrically in accordance with DSTU ISO 10390-2001 [19; 20]; determination of hydrolytic acidity – by the Kappen method in accordance with DSTU 7537:2014 [21; 22]; determination of the content of hydrolyzed nitrogen in the soil – by the Kornfield method according to DSTU 7863:2015 [13; 23]; determination of the content of mobile forms of phosphorus and potassium in the soil – by Chirikov's methods according to DSTU 4115-2002 [12; 19; 24]; determination of the amount of absorbed bases in the soil – according to Kappen-Hilkovits.

Research was conducted during 2018–2021 on gray podzolized medium loamy soils of FG "Zorya Vasylivka" of Tyvriv district, Vinnytsia region. The experimental field of FG "Zorya Vasylivka", where the field research was carried out, is located in the central part of Vinnytsia region in the Central Forest Steppe and is located almost on the border of two geomorphological regions: the Letychiv-Lytyna ancient alluvial and water-glacial depression and the Vinnytsia denudation-accumulative undulating plain of the Dnieper Highlands.

4. Research results

The use of siderates of the main agricultural crops: winter wheat, spring barley, winter peas and rapeseed, grown under conditions of intensive agriculture, had a positive effect on the change in soil fertility indicators, compared to the option without growing siderates during the crop rotation period. The main indicators of soil fertility include: the content of humus, easily hydrolyzable nitrogen, mobile phosphorus, exchangeable potassium, soil pH reaction, hydrolytic acidity, the sum of absorbed bases, and others.

In particular, the humus content was 2.30% in the variant without growing siderates. Cultivation of siderates during the crop rotation period contributed to an increase in the humus content of the soil by 0.11-0.14%. The humus content increased the most in the option of growing siderates of winter peas and rapeseed, and the least – in spring barley. In general, the highest content of humus was found in the option of growing winter pea and rapeseed – 2.44% each, and the lowest – in the case of growing spring barley siderate – 2.41% (Table 1). According to the content of humus, all studied options were in the range of "average content" (2.1-3.0%).

The content of alkaline hydrolyzed nitrogen in the version without growing siderates was 118 mg/kg. When growing siderates, the content of alkaline hydrolyzed nitrogen in the soil increased by 1.7-7.1%. The content of alkaline hydrolyzed nitrogen in the soil increased most significantly after the cultivation of pea siderate, and the least – after spring barley and winter rape. The highest content of alkaline hydrolyzed nitrogen was found in the soil where pea siderate was grown – 127 mg/kg, and the lowest – after growing spring barley siderate and winter rapeseed – 120 mg/kg each. According to the content of alkaline hydrolyzed nitrogen in the soil, all the tested options were in the "low content" range (100-150 mg/kg).

Table 1

The influence of siderates on soil fertility indicators, 2021, M±m

Agrochemical indicators of the soil	Siderates				
	wheat winter	**barley is hot**	**pea**	**winter rape**	**without siderates**
Humus, %	2,42±0,02	2,41±0,02	2,44±0,01	2,44±0,01	2,30±0,03
Alkaline hydrolyzed nitrogen, mg/kg	125±2	120±3	127±2	120±3	118±3
Mobile phosphorus, mg/kg	520±4	510±2	515±3	517±3	622±3
Exchangeable potassium, mg/kg	215±2	218±2	220±1	230±1	156±4
Soil reaction, pH	5,75±0,02	5,85±0,03	5,65±0,01	5,55±0,02	6,05±0,03
Hydrolytic acidity, mg-eq./100 g	1,60±0,04	1,65±0,04	1,70±0,03	1,72±0,03	1,60±0,02
Sum of absorbed bases, mgeq./100 g	16,2±0,4	16,4±0,2	16,8±0,3	16,4±0,2	17,5±0,2

The concentration of mobile phosphorus in the control variant without growing siderats was 622 mg/kg and was the highest among all studied options where siderats were grown. On the variants with the cultivation of sideral crops, the content of mobile phosphorus in the soil decreased by 16.4-18.0%. The smallest decrease in the content of mobile phosphorus in the soil, compared to the option without the use of siderates, was found in the option of growing siderates of winter wheat, and the largest decrease was found in the option of growing siderates of spring barley. In general, the lowest content of mobile phosphorus in the soil was found after growing spring barley siderate – 510 mg/kg, and the highest – after growing winter wheat siderate – 520 mg/kg. According to the content of mobile phosphorus in the soil, all the studied variants are in the "average content" category (51-100 mg/kg).

The soil of the variant without siderate cultivation contained exchangeable potassium of 156 mg/kg. Cultivation of siderates helped to increase the content of exchangeable potassium in the soil by 27.4-32.2%. The greatest increase in the content of exchangeable potassium in the soil was found in the option of growing winter rapeseed, and the least – growing winter wheat. The highest content of exchangeable potassium in the soil was established on the option of growing winter rapeseed – 230 mg/kg, and the lowest – after winter wheat siderate – 215 mg/kg. In the control option, without growing siderate, the content of exchangeable potassium in the soil corresponded to the "high content" indicator (120-180 mg/kg), and in the remaining options, where siderates were grown, to the "very high" indicator (over 180 mg/kg).

The pH reaction of the soil on the option without growing siderates was 6.05 pH. Variants with the cultivation of siderates were marked by a decrease in the reaction value of the soil solution by 0.2-0.5 pH. This indicates acidification of the soil when growing siderats. The greatest acidification of the soil is observed after the cultivation of winter rape seed extract, and the least – after spring barley seed extract. In general, the highest pH value of the reaction of the soil solution on the variants with the cultivation of siderates was found after spring barley – 5.85 pH, and the lowest – after winter rape – 5.55 pH. According to the reaction of the pH of the soil solution, the version with siderate cultivation of winter rapeseed had a slightly acidic reaction (5.10-5.55 pH), the other options with siderate cultivation were close to neutral (5.6-6.0 pH), while as an option without growing siderates, it had a neutral pH reaction (6.05-7.00 pH).

The hydrolytic acidity of the soil in the variant without growing siderates and when growing siderates of winter wheat was the same and amounted to 1.60 mg-eq./100 g. In other variants of growing siderates, the value of hydrolytic acidity of the soil increased by 3.0-7.0%. The largest increase in hydrolytic acidity was found in the variant of growing winter rapeseed, where the actual hydrolytic acidity of the soil was the highest and amounted to 1.72 mg-eq./100 g.

The amount of absorbed soil bases in the variant without growing siderates was the highest and amounted to 17.5 mg-equiv./100 g. When growing siderates, the amount of absorbed soil bases decreased by 4.0-7.4%. The amount of absorbed bases in the soil, where siderate winter wheat was grown, decreased most significantly, and peas the least. The largest value of the amount of absorbed soil bases was found in the variant where pea siderate was grown – 16.8 mg-equiv./100 g, and the lowest – when growing winter wheat siderate – 16.2 mg-equiv./100 g.

Therefore, the conducted research established that the cultivation of winter wheat, spring barley, winter pea and winter rapeseeds had a positive effect on increasing the humus content in the soil by 0.11-0.14%, which is due to the accumulation of organic matter in the soil formed by siderates and its gradual transformation into humus. The same regularity is observed in the content of alkaline hydrolyzed nitrogen and exchangeable potassium in the soil, which are formed from the organic mass of siderates.

At the same time, the content of mobile phosphorus in the soil when growing siderates was lower than in the version without siderates. This can be explained by the fact that siderates removed mobile phosphorus from the soil for their growth and development, but did not return it in a form available to plants.

The reaction of the pH of the soil solution and the hydrolytic acidity of the soil during the cultivation of siderates moves in the direction of soil acidification, which can be explained by the extraction of calcium siderates from the soil. This statement is substantiated by the fact of a decrease in the amount of absorbed soil bases when growing siderates.

Thus, the cultivation of siderates of winter wheat, spring barley, peas and winter rape helps to increase the content of humus in the soil by 0.11-0.14%, alkaline hydrolyzed nitrogen – by 1.7-7.1%, exchangeable potassium – by 27, 4-32.2%, but a decrease in the content of mobile phosphorus – by 16,418.0%, acidification of the reaction of the soil solution – by 0.2-0.5 pH, an increase in hydrolytic acidity to 7.0% and a decrease in the amount of absorbed bases by 4, 0-7.4%.

In particular, the cultivation of pea siderate, compared to other studied siderates, contributes to the greatest increase in the content of humus and alkaline hydrolytic nitrogen in the soil and the formation of the highest amount of absorbed bases. Cultivation of siderate of winter rapeseed allows the greatest increase in the content of humus in the soil, exchangeable potassium, but causes the least increase in the content of alkaline hydrolyzable nitrogen, the greatest acidification of the reaction of the soil pH solution and increases hydrolytic acidity. Cultivation of siderate of winter wheat provides the greatest increase in the content of mobile phosphorus in the soil, the greatest decrease in the value of hydrolytic acidity, but allows to obtain the smallest increase in exchangeable potassium in the soil and the lowest value of the sum of absorbed bases. Spring barley, as a siderate, provides the smallest increase in the content of humus in the soil and alkaline hydrolyzed nitrogen, the lowest content of mobile phosphorus, but the most neutral reaction of the soil pH, compared to other studied sideral crops.

A strong positive correlation r = 0.988 was established between the biological mass of siderate plants and their influence on the growth of humus content in the soil. The diagram of the correlation-regression dependence of the studied factors is shown in Figure 1.

The coefficient of determination $R^2 = 0.976$ shows that the increase in humus content in the soil depends on the yield of siderates by 98%.

An average positive correlation of r = 0.534 was established between the biological mass of siderate plants and their influence on the growth of alkaline hydrolyzed nitrogen content in the soil. The reason for this is the increase in nitrogen content in the soil on the variant where siderate peas grew due to its symbiotic nitrogen fixation.

A strong positive correlation r = 0.984 was established between the biological mass of siderate plants and their influence on the growth of exchangeable potassium content in the soil. The diagram of the correlation-regression dependence of the studied factors is shown in Figure 2.

The coefficient of determination $R^2 = 0.968$ shows that the increase in the content of exchangeable potassium in the soil depends on the yield of siderates by 97%.

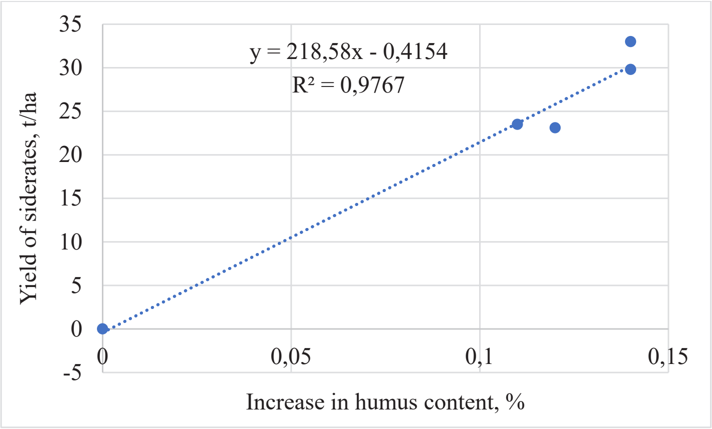

Figure 1. Correlation-regression relationship between the increase in humus content in the soil (x) and the yield of siderates (y)

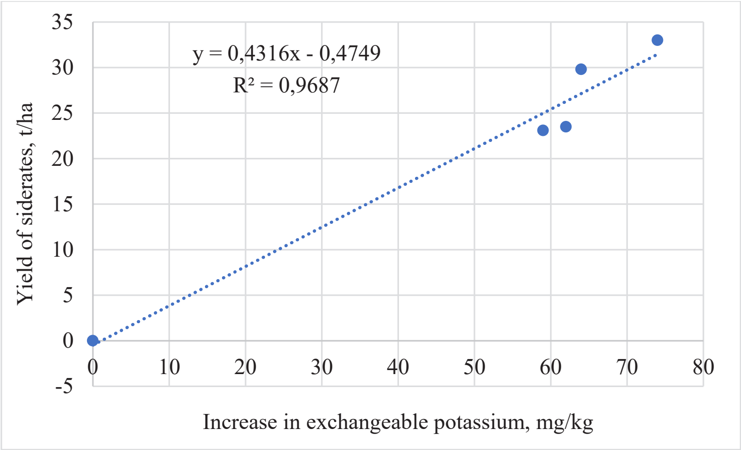

Figure 2. Correlation-regression relationship between the increase in the content of exchangeable potassium in the soil (x) and the yield of siderates (y)

The concentration of mobile forms of heavy metals: lead, cadmium, copper and zinc during the cultivation of siderates also underwent changes. In particular, the lead content in the soil for growing siderats was 1.28-1.40 mg/kg. The lowest content of mobile forms of lead in the soil was found in the variant of growing winter rapeseed, and the highest – when growing spring barley. Compared to the site where siderates were not grown, the content of mobile forms of lead in the soil on the version with siderates increased by 17.2-24.3%. However, the maximum allowable concentration of mobile forms of lead in the soil (6.0 mg/kg) is significantly higher than the actual content in the soil of the experimental sites, which does not pose a danger (Table 2).

Table 2

The influence of siderates on the content of mobile forms of heavy metals in the soil, 2021 mg/kg, M±m

Heavy metals	MPC of heavy metals	Siderates				
		wheat winter	wheat winter	wheat winter	wheat winter	wheat winter
Pb	6,0	1,35±0,04	1,40±0,03	1,38±0,03	1,28±0,02	1,06±0,02
Cd	0,7	0,21±0,01	0,21±0,01	0,21±0,01	0,20±0,01	0,18±0,01
Cu	3,0	0,54±0,03	0,53±0,03	0,51±0,02	0,51±0,02	0,42±0,02
Zn	23,0	1,82±0,05	1,73±0,03	1,88±0,05	1,82±0,04	1,13±0,02

The concentration of cadmium in the soil during the cultivation of siderates was 0.20-0.21 mg/kg. The lowest cadmium content was found in the winter rapeseed siderate cultivation option, and in the remaining siderates – 0.21 mg/kg. In the variant without growing siderates, the concentration of mobile forms of cadmium was 10.0-14.3% lower and amounted to 0.18 mg/kg. The maximum permissible concentration of mobile forms of cadmium in the soil is 0.7 mg/kg, which is much higher than the actual concentration of cadmium in the soil of the tested options, so there is no danger.

The content of mobile forms of copper in the soil where siderates were grown was 0.51-0.54 mg/kg. The lowest copper content was found in the option of growing siderates of winter peas and rapeseed, and the highest – in the option of growing siderates of winter wheat. In the variant without growing siderates, the copper content in the soil was 17.6-22.2% lower and amounted to 0.42 mg/kg. Maximum permissible limit for copper in soil is 3.0 mg/kg. The actual content of copper in the soil of the experimental variants was much lower.

The concentration of mobile forms of zinc in the soil where siderates were grown was 1.73-1.88 mg/kg. The lowest content of mobile forms of zinc was found in the soil where spring barley siderate was grown, and the highest – where pea siderate was grown. The concentration of zinc on the control option without growing siderats was 1.13 mg/kg, which was 34.7-39.9% less than on the options for growing siderats. The maximum allowable concentration of zinc in the soil is 23.0 mg/kg, which was significantly less than in the experimental variants.

An important indicator that determines the ecological danger of the content of heavy metals in the soil relative to the maximum permissible concentration is the danger coefficient, which is determined by the ratio of the actual concentration of heavy metals in the soil to their MPC. The obtained value should be less than one, this indicates satisfactory environmental conditions. The smaller the indicator, the safer the ecological situation.

The hazard ratio of lead in the soil when growing siderats was 0.21-0.23. It was the smallest when growing winter rapeseed. On the option without growing siderats, the hazard ratio was slightly lower and amounted to 0.18 (Figure 3).

The lowest cadmium hazard ratio when growing siderates was on the winter rapeseed variant – 0.29, and on the remaining variants – the same – 0.3. This is slightly more than in the option without growing siderates – 0.26 (Figure 4).

The lowest coefficient of danger of copper in the soil during the cultivation of siderats was established on the version of peas and winter rape – 0.17 each.

The highest risk factor was established for the siderate cultivation option of winter wheat and spring barley – 0.18 each. The hazard ratio of copper in the option without growing siderates was the lowest and amounted to 0.14 (Figure 5).

The lowest zinc hazard ratio was found on the variant without siderate cultivation – 0.05. In the remaining experimental variants, it was the same after growing all siderates and amounted to 0.08 (Figure 6).

Since soil contamination with several heavy metals was determined at the same time (lead, cadmium, copper and zinc), it is necessary to calculate the total pollution index, which takes into account the complex impact of

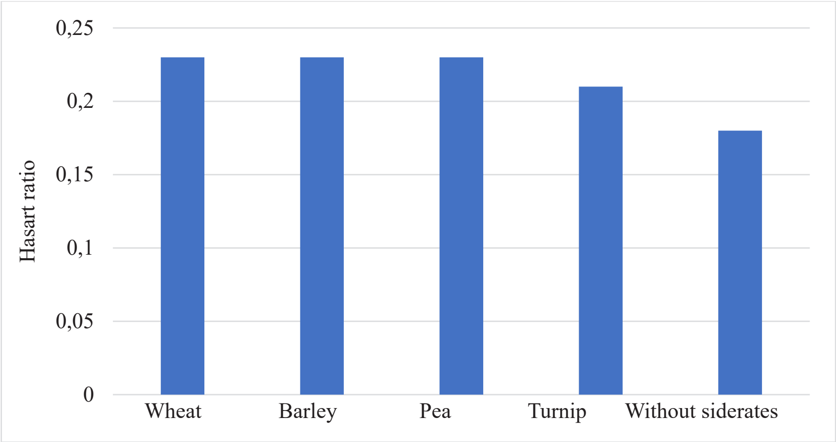

Figure 3. The risk factor of lead in the soil when growing siderats

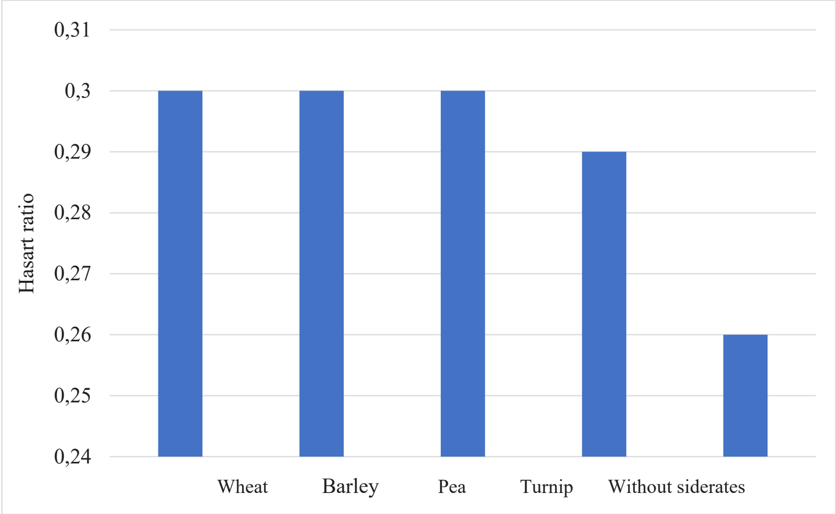

Figure 4. The hazard ratio of cadmium in the soil when growing siderats

all heavy metals on the ecological state of the soil environment, according to the formula:

$$Zc = (Kc1 + Kc2 + Kc3 + Kc4) - (n - 1),$$

where: Zc is the total indicator of soil pollution; Kc is the hazard ratio of a heavy metal; n is the number of heavy metals taken into account.

Such a calculation will show which siderate has the most positive effect on reducing the concentration of several heavy metals at the same time. The lower the obtained number, the more favorable the environmental impact of siderate on reducing the danger of heavy metals in the soil.

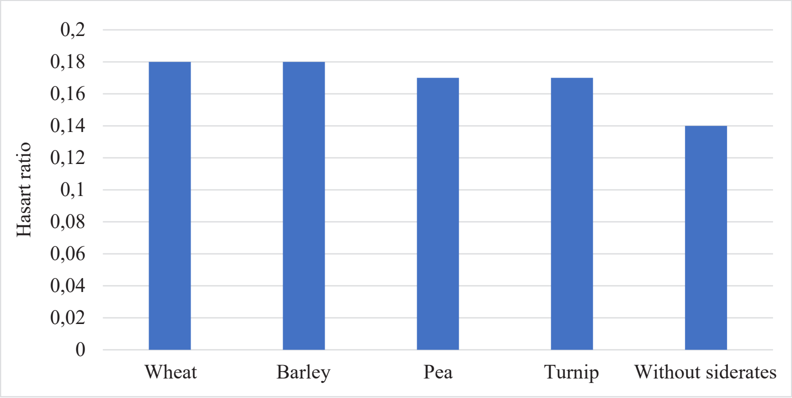

Figure 5. The danger coefficient of copper in the soil when growing siderats

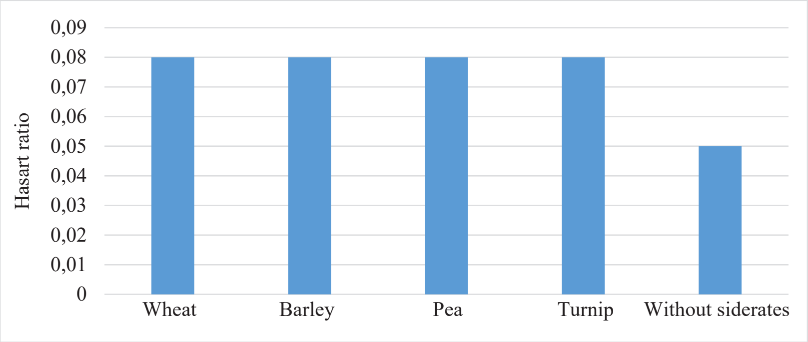

Figure 6. The hazard ratio of zinc in the soil when growing siderates

All studied siderates provided very low values of the total indicator of soil contamination with several heavy metals with negative values. The lowest total indicator was provided by the siderate of winter rape – minus 2.25, and the highest – b y the siderates of winter wheat and spring barley – minus 2.21 each. In the variant without growing siderates, the total indicator of soil contamination by several heavy metals was even lower – minus 2.37 (Figure 7).

On the basis of research conducted on the effectiveness of growing siderates for reducing the content of mobile forms of heavy metals in the soil, it can be stated that the cultivation of siderates of winter wheat, spring barley, peas and winter rape leads to an increase in the content of lead in the soil by 17.2-24.3%. cadmium – by 10.0-14.3%, copper – by 17.6-22.2% and zinc – by 34.7-39.9%, compared to the option without growing siderates, which is explained by the conversion of hard-to-reach substances into soil in easily soluble mobile compounds, which also applies to heavy metals. That is, difficult-to-dissolve compounds of heavy metals that were in the soil are transformed into easily-soluble ones – available to plants when growing siderates, but there is no harm to plants at such concentrations.

Among the investigated siderates, the lowest content of lead, cadmium and copper in the soil is provided by winter rapeseed. Also, this option allows you to get the lowest amount of total soil contamination with four

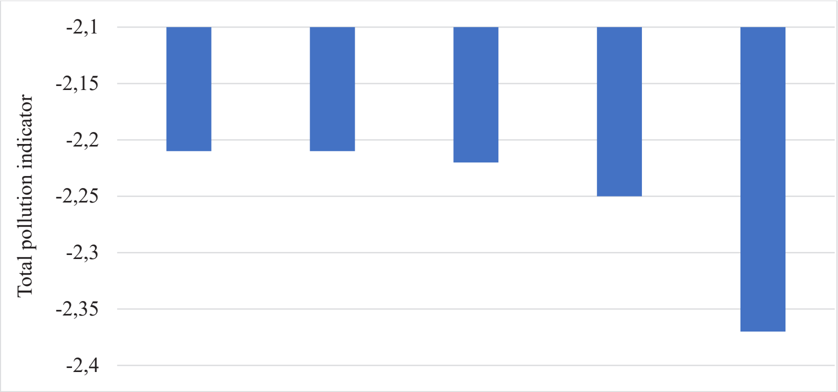

Figure 7. Total indicator of soil contamination with several heavy metals during the cultivation of siderats

types of heavy metals. Siderate peas provide the lowest copper content in the soil, but the highest zinc content. Spring barley siderate provides the highest content of lead in the soil, but the lowest – of zinc, as well as the highest amount of total contamination of the soil with all heavy metals. Siderate winter wheat provides the highest content of copper in the soil and the highest total indicator of soil contamination with all heavy metals.

5. Conclusions

The most positive effect of the investigated siderates on soil fertility indicators was exerted by peas, which increased the content of humus by 0.14%, easily hydrolyzed nitrogen by 7% compared to the control; winter rape – increased the content of humus by 0.14%, exchangeable potassium – by 32.2% compared to the control; winter wheat – increased the content of mobile phosphorus among all siderates. The most positive effect on the reduction of the content of mobile forms of heavy metals in the soil was exerted by winter rapeseed crops for lead, cadmium and copper; spring barley – for zinc; peas – for copper.

References:

1. Bondarenko V., Havrylianchik R., Ovcharuk O., Pantsyreva H., Krusheknyckiy V., Tkach O. and Niemec M. (2022) Features of the soybean photosynthetic productivity indicators formation depending on the foliar nutrition. *Ecology, Environment and Conservation*, 28, 20–26. DOI: https://doi.org/10.53550/EEC.2022.v28i04s.004

2. Didur I., Bakhmat M., Chynchyk O., Pantsyreva H., Telekalo N., Tkachuk O. (2020). Substantiation of agroecological factors on soybean agrophytocenoses by analysis of variance of the Right-Bank Forest-Steppe in Ukraine. *Ukrainian Journal of Ecology*, 10(5), 54–61.

3. Didur I., Chynchyk O., Pantsyreva H., Olifirovych S., Olifirovych V., Tkachuk O. (2021). Effect of fertilizers for Phaseolus vulgaris L. productivity in Western Forest-Steppe of Ukraine. *Ukrainian Journal of Ecology*, 11 (1), 419–424. DOI: https://doi.org/10.15421/2021_61

4. Didur, I., Bakhmat M., Chynchyk O., Pantsyreva H., Telekalo N., Tkachuk O. (2020). Substantiation of agroecological factors on soybean agrophytocenoses by analysis of variance of the Right-Bank Forest-Steppe in Ukraine. *Ukrainian Journal of Ecology*, 10(5), 54–61.

5. Didur, I.M., Prokopchuk, V.M., Pantsyreva H.V. (2019). Investigation of biomorphological and decorative characteristics of ornamental species of the genus Lupinus L. *Ukrainian Journal of Ecology*, 9(3), 287–290. DOI: https://doi.org/10.15421/2019_743

6. Honcharuk I., Matusyak M., Pantsyreva H., Kupchuk I., Prokopchuk V., Telekalo N. (2022). Peculiarities of reproduction of pinus nigra arn. in Ukraine. *Bulletin of the Transilvania University of Brasov. Series II: Forestry, Wood Industry, Agricultural Food Engineering,* 15 (64), 1, 33–42.

7. Honcharuk I., Pantsyreva H. (2020). Efficiency of growing legumes crops in Ukraine. Collective monograph. Riga, Latvia: Publishing House "Baltija Publishing", pp. 42–65.

8. Honcharuk I., Pantsyreva H., Mazur V., Didur I., Tkachuk O., Telekalo N. (2020). Integration of traditional and innovation processes of development of modern science. Collective monograph. Riga, Latvia: Publishing House "Baltija Publishing", pp. 42–108.

9. Matusyak M.V., Pantsyreva H.V., Prokopchuk V.M. (2021). Assessment of decorative value and prospects of the genus Magnolia compositional use on the territory of Vinnytsia. *Agriculture and forestry*, 4 (23), 137–147.

10. Mazur V.A., Myalkovsky R.O., Pantsyreva H.V., Didur I.M., Mazur K.V., Alekseev O.O. (2020). Photosynthetic productivity of potato plants depending on the location of rows placement in agrophytocenosis. *Eco. Env. & Cons*., 26 (2), 46–55.

11. Mazur V., Didur I. (2020). Legumes are strategic factor in regulating protein balance and soil fertility: collective monograph. Riga, Latvia: Publishing House "Baltija Publishing", pp. 66–90.

12. Mazur V., Didur I., Myalkovsky R., Pantsyreva H., Telekalo N., Tkach O. (2020). The Productivity of intensive pea varieties depending on the seeds treatment and foliar fertilizing under conditions of right-bank forest- steppe Ukraine. *Ukrainian Journal of Ecology*, no. 10 (1), pp. 101–105. DOI: https://doi.org/10.15421/2020_16

13. Mazur V., Pantsyreva H., Mazur K., Myalkovsky R., Alekseev O. (2020). Agroecological prospects of using corn hybrids for biogas production. *Agronomy Research*, vol. 18, pp. 205–219.

14. Mazur V., Tkachuk O., Pantsyreva H., Demchuk O. (2021). Quality of pea seeds and agroecological condition of soil when using structured water. *Scientific Horizons,* 24(7), 53–60.

15. Mazur V.A., Didur I.M., Pantsyreva H.V., Telecalo N.V. (2018). Energy-economic efficiency of growth of grain-crop cultures in the conditions of right-bank Forest-Steppe zone of Ukraine. *Ukrainian Journal of Ecology*, vol. 8, no. 4, pp. 26–33.

16. Mazur V.A., Mazur K.V., Pantsyreva G.V. (2022). Production and export of grain and leguminous crops under martial law. *Agriculture and forestry*, 3 (26), 66–76. DOI: https://doi.org/10.37128/2707-5826-2022-3-5

17. Mazur V.A., Mazur K.V., Pantsyreva H.V., Alekseev O.O. (2018). Ecological and economic evaluation of varietal resources Lupinus albus L. in Ukraine. *Ukrainian Journal of Ecology*, 8, 148–153.

18. Mazur V.A., Myalkovsky R.O., Pantsyreva H.V., Didur I.M., Mazur K.V., Alekseev O.O. (2020). Photosynthetic productivity of potato plants depending on the location of rows placement in agrophytocenosis. *Ecology, Environment and Conservation*, vol. 26, no. 2, pp. 536–545.

19. Mazur, V.A., Myalkovsky, R.O., Mazur, K.V., Pantsyreva, H.V., Alekseev, O.O. (2019). Influence of the Photosynthetic Productivity and Seed Productivity of White Lupine Plants. *Ukrainian Journal of Ecology*, 9(4), 665–670. DOI: https://doi.org/10.15421/2019_807

20. Mazur, V.A. (2018). Primary introduction assessment of decorative species of the lupinus generation in Podillya. *Scientific Bulletin of UNFU*, 28(7), 40–43. DOI: https://doi.org/10.15421/40280708

21. Mazur, V., Didur, I., Myalkovsky, R., Pantsyreva, H., Telekalo, N., Tkach, O. (2020). The Productivity of intensive pea varieties depending on the seeds treatment and foliar fertilizing under conditions of right-bank forest-steppe Ukraine. *Ukrainian Journal of Ecology,* 10(1), 101–105.

22. Mazur, V.A., Branitskyi, Y.Y., Pantsyreva, H.V. (2020). Bioenergy and economic efficiency technological methods growing of switchgrass. *Ukrainian Journal of Ecology*, 10(2), 8–15.

23. Mazur, V.A., Pantsyreva, H.V., Mazur, K.V., & Monarkh, V.V. (2019). Ecological and biological evaluation of varietal resources Paeonia L. in Ukraine. *Acta Biologica Sibirica*, 5 (1), 141–146. DOI: https://doi.org/10.14258/abs.v5.i1.5350

24. Monarkh V.V., Pantsyreva H.V. (2019). Stages of the Environmental Risk Assessment. *Ukrainian Journal of Ecology*, 9(4), 484–492. DOI: https://doi.org/10.15421/2019_779

25. Oleksandr Tkachuk, Myroslava Mordvanyuk (2022). Study of the influence of unfavorable vegetation conditions on agro-ecological resistance of bean varieties. Theoretical and practical aspects of the development of modern scientific research: Scientific monograph. Riga, Latvia: Publishing House "Baltija Publishing", pp. 109–125.

26. Olexander Tkachuk, Myroslava Mordvaniuk (2021). Research of technological indicators of grain quality of legumes as objects of storage and processing. Development of scientific, technological and innovation space in Ukraine and EU countries. Riga, Latvia: "Baltija Publishing", pp. 221–240.

27. Pantsyreva H., Stroyanovskiy V., Mazur K., Chynchyk O., Myalkovsky R. (2021). The influence of bio-organic growing technology on the productivity of legumins. *Ukrainian Journal of Ecology*, 11 (3), 35–39. DOI: https://doi.org/10.15421/2021_139

28. Pantsyreva, H.V. (2019). Morphological and ecological-biological evaluation of the decorative species of the genus Lupinus L. *Ukrainian Journal of Ecology*, 9(3), 74–77. DOI: https://doi.org/10.15421/2019_711

29. Pantsyreva H.V., Myalkovsky R.O., Yasinetska I.A., Prokopchuk V.M. (2020). Productivity and economical appraisal of growing raspberry according to substrate for mulching under the conditions of podilia area in Ukraine. *Ukrainian Journal of Ecology*, 10(1), 210–214.

30. Puyu V., Bakhmat M., Pantsyreva H., Khmelianchyshyn Y., Stepanchenko V., Bakhmat O. (2021). Social-and-Ecological Aspects of Forage Production Reform in Ukraine in the Early 21st Century. *European Journal of Sustainable Development*, 10(1), 221–228.

31. Razanov S.F., Tkachuk O.P., Mazur V.A., Didur I.M. (2018). Effect of bean perennial plants growing on soil heavy metal concentrations. *Ukrainian Journal of Ecology*, 8(2), 294–300. DOI: https://doi.org/10.15421/2018_341

32. Razanov S.F., Tkachuk O.P., Bakhmat O.M., Razanova A.M. (2020). Reducing danger of heavy metals accumulation in winter wheat grain which is grown after leguminous perennial precursor. *Ukrainian Journal of Ecology*, 10(1), 254–260. DOI: https://doi.org/10.15421/2020_40

33. Razanov S.F., Tkachuk O.P., Ovcharuk V.V., Ovcharuk I.I. (2021). The effect of siderates on soil fertility. *Balanced environmental management*, 4, 144–152.

34. Razanov S.F., Tkachuk O.P., Razanova A.M., Bakhmat M.I., Bakhmat O.M. (2020). Intensity of heavy metal accumulation in plants of Silybum marianum L. in conditions of field rotation. *Ukrainian Journal of Ecology*, 10(2), 131–136. DOI: https://doi.org/10.15421/2020_75

35. Tkachuk O., Verhelis V. (2021) Intensity of soil pollution by toxic substances depending on the degree of its washout. *Scientific Horizons*, vol. 24, no. 3, pp. 52–57.

36. Tkachuk O.P. (2022). Prerequisites for the transition of agriculture in Ukraine to ecologically balanced principles. *Environmental sciences*, 5 (44), 144–149.

37. Tkachuk O.P., Vradiy O.I. (2022). The balance of nutrients in the soil during the cultivation of leguminous crops. *Environmental sciences*, 2 (41), 43–47.

38. Tkachuk O. (2021). Biological features of the distribution of root systems of perennial legume grasses in the context of climate change. *Scientific Horizons*, 24(2), 70–76.

39. V.A. Mazur, H.V. Pantsyreva, K.V. Mazur and I.M. Didur (2019). Influence of the assimilation apparatus and productivity of white lupine plants. *Agronomy Research*, 17, 206–219.

40. V.A. Mazur, K.V. Mazur, H.V. Pantsyreva (2019). Influence of the technological aspects growing on quality composition of seed white lupine (Lupinus albus L.) in the Forest Steppe of Ukraine. *Ukrainian Journal of Ecology*, 9, 50–55.

41. Vdovenko S.A., Palamarchuk I.I., Pantsyreva H.V. and ets. (2018). Energy efficient growing of red beet in the conditions of central forest steppe of Ukraine. *Ukrainian Journal of Ecology*, 8, 34–40.

42. Vdovenko S.A., Pantsyreva H.V., Palamarchuk I.I., Lytvynuk H.V. (2018). Symbiotic potential of snap beans (Phaseolus vulgaris L.) depending on biological products in agrocoenosis of the RightBank Forest-steppe of Ukraine. *Ukrainian Journal of Ecology,* 8 (3), 270–274.

43. Vdovenko S.A., Procopchuk V.M.., Palamarchuk I.I., Pantsyreva H.V. (2018). Effectiveness of the application of soil milling in the growing of the squash (Cucurbita pepo var. giraumontia) in the right-benk forest stepp of Ukraine. *Ukrainian Journal of Ecology*, 8 (4), 1–5.

44. Victor Mazur, Oleksandr Tkachuk, Hanna Pantsyreva, Ihor Kupchuk, Myroslava Mordvaniuk, Oleksandr Chynchyk (2021). Ecological suitability peas (Pisum sativum) varieties to climate change in Ukraine. Agraarteadus. *Journal of Agricultural Science*, no. 2, vol. XXXII, pp. 276–283.

45. Viktor Mazur, Ihor Didur, Oleksandr Tkachuk, Hanna Pantsyreva, Vitaliy Ovcharuk (2021). Agroecological stability of cultivars of sparsely distributed legumes in the context of climate change. *Scientific Horizons*, vol. 24, no. 1, pp. 54–60.