UDC 631.45/631.95
DOI https://doi.org/10.32782/2226-0099.2023.132.26

INFLUENCE OF FERTILIZERS ON INDICATORS OF THE AGRO-ECOLOGICAL CONDITION OF THE SOIL

Tkachuk O.P. *– Doctor of Agricultural Sciences, Professor,*
Head of Department of Ecology and Environmental Protection,
Vinnytsia National Agrarian University
Verhelis V.I. *– Assistant at the Department of Ecology and Environmental Protection,*
Vinnytsia National Agrarian University

The work is devoted to the study of the expediency of using carrion siderates for indicators of the agro-ecological condition of the soil. The research was intended to study the influence of carrion siderates, which spontaneously sprouted after the loss of crop yields and disking of the field, on indicators of productivity, product quality and its ecological safety of corn and sunflower, as the next crops in the crop rotation, as well as on indicators of fertility and agro-ecological condition of soils. Experimental research was carried out in the conditions of FG "Zorya Vasylivka" of the Tyvriv district of the Vinnytsia region on gray podzolized soils.

Provision of favorable agrotechnical conditions for the growth of fallow siderates of winter wheat, spring barley, peas and winter rape can provide them with a biological mass of 23.1 –33.0 t/ha at a height of 22–64 cm during the 63–91 days of their vegetation. The most productive can to be ciders of winter rapeseed and peas.

It was established that the biological mass of carrion 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 number 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.

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.

Key words: *siderates, agroecological condition of the soil, nutrients.*

Ткачук О.П., Вергеліс В.І. Вплив добрив на показники агроекологічного стану ґрунту

Робота присвячена вивченню доцільності використання падалишних сидератів для поліпшення агроекологічного стану ґрунту. Метою досліджень було вивчити вплив падалишних сидератів, що спонтанно проросли після втрати врожаю та дискування поля, на показники врожайності, якості продукції та екологічної безпеки кукурудзи та соняшнику, як наступних культур у сівозміні, а також за показниками родючості та агроекологічного стану ґрунтів. Експериментальні дослідження проводили в умовах ФГ «Зоря Василівка» Тиврівського району Вінницької області на сірих опідзолених ґрунтах.

Забезпечення сприятливих агротехнічних умов для росту сидератів озимої пшениці, ярого ячменю, гороху та ріпаку озимого може забезпечити їх біологічну масу 23,1–33,0 т/га при висоті 22–64 см протягом 63–91 дня їх вегетації. Найбільш продуктивними можуть бути сидерати озимого ріпаку та гороху.

Встановлено, що внесена в ґрунт біологічна маса падалишних сидератів сприяє збільшенню вмісту гумусу на 0,11–0,14 %, гідролізованого азоту – на 1,7–7,1 %, обмінного калію – на 27,4–32,2 %. Найбільший вміст гумусу в ґрунті забезпечують сидерати гороху та озимого ріпаку – по 2,44 %, азоту лужного гідролізованого – 127 мг/кг – гороху, рухомого фосфору – 520 мг/кг – озимої пшениці, обмінного калію – 230 мг/кг – озимий ріпак, найбільша кількість увібраних основ – 16,8 мг-екв./100 г – горох, найменша гідролітична кислотність – 1,60 мг-екв./100 г – озима пшениця, найбільше значення рН 5,85 – ярий ячмінь.

Визначено, що вирощування сидератів призводить до збільшення вмісту в ґрунті рухомих форм важких металів на 17,2–24,3 %, кадмію – на 10,0–14,3 %, міді – на 17,6–22,2 %, цинку – на 34,7–39,9 %, порівняно з варіантом без сидератів. Серед досліджуваних сидератів найменший вміст у ґрунті свинцю – 1,28 мг/кг та кадмію – 0,20 мг/кг забезпечує озимий ріпак; міді – 0,51 мг/кг – горох та озимий ріпак; цинк – 1,73 мг/кг – ячмінь ярий.
Ключові слова: *сидерати, агроекологічний стан ґрунту, елементи живлення.*

Problem statement. 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 [1].

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 [2].

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 [3].

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 [4].

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 V. Artemenko (2003), O.M. Berdnikov. (2004), G.A. Makarova (2008), H.M. Gospodarenko (2012–2016), S.F. Razanov (2020) and others [5].

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 crop production waste on the quality and ecological safety of the grown products, has not been studied enough, which determines the relevance of the chosen topic [6].

Analysis of recent research. 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 the 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 [7].

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 [8].

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 [9].

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, i.e., 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 other organic fertilizers, both dry (straw) and partially decomposed (manure), applied to the soil [10].

"Sideration" and "green fertilizer" are rather conventional names; the first of them reflects the role of the sun's rays (sidereus – related to heavenly bodies), and the second – the role of chlorophyll-bearing green organs of plants and the measure of plowing green mass into the soil, which is also called green fertilization [11].

In English-language literature, the term "cover crops" is more common. It is understood as crops that are grown primarily to create a plant cover, regardless of whether the plant mass will be incorporated into the soil in the future as organic green manure or will remain on the soil surface in the form of plant residues. The importance of their application will depend on the correctly defined main task, which must be solved at the expense of the grown cover crops and their justified selection for this purpose. As for the terms "green fertilizer", "sidereal fertilizer", which can be used as cover crops, they are interpreted in the same way in our and English-language scientific literature [12].

Also, the use of fodder and siderable crops to create favorable conditions for the development of one or a group of crops in a biological farming system is called "environmental improvement", and the plants themselves, which are grown for this purpose, are called "environmentally improved fodder crops", "environmentally improved fodder crops" and "environmentally improved siderable crops" [13].

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, sow trefoil, burgun and sweet clover [14].

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 soil fertilized with nitrogen accumulated by leguminous plants does not require additional costs [15].

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 have been used by plants to create a crop, the application 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 [16].

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 [17].

Plants should be sown on green manure in order to obtain as much organic mass as possible. Therefore, they should produce large yields. Green manure is usually used on poor soils, and therefore the plants must be undemanding to soil conditions. It is also important to choose such a sidereal crop that would have a low transpiration coefficient (to save soil moisture), a low seeding rate (to reduce seed costs) and, along with the formation of a high biomass yield, would ensure an early period of earning it in the soil. It is essential that sideral vapors should be used not only on poor sandy and loamy soils in areas with sufficient moisture (in the Ukrainian Polity), but also on soils with a heavy granulometric composition [18].

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.

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, safflower, lentils, horse beans, gorse, sabdar, bers, soybean, rye, paiza, Sudan grass and many others can be used as side crops [19].

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.

Task setting. The research was intended to study the influence of carrion siderates, which spontaneously sprouted after the loss of crop yields and disking of the field, on indicators of productivity, product quality and its ecological safety of corn and sunflower, as the next crops in the crop rotation, as well as on indicators of fertility and agro-ecological condition of soils.

Experimental research was carried out in the conditions of FG “Zorya Vasylivka” of the Tyvriv district of the Vinnytsia region on gray podzolized soils.

The following observations, records and measurements were carried out: determination of soil pollution by mobile forms of heavy metals, indicators of soil fertility, the content of heavy metals in corn and sunflower seeds, the content of protein, starch, fat in sunflower seeds, oil in sunflower seeds, acid number of oil and grain moisture and seeds were 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; determination of the content of humus in the soil – according to the Tyurin method in accordance with DSTU 4289:2004; 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; determination of soil pH salt reaction – ionometrically in accordance with DSTU ISO 10390–2004; determination of hydrolytic acidity – by the Kappen method in accordance with DSTU 7537:2014; determination of the content of hydrolyzed nitrogen in the soil – by the Kornfield method according to DSTU 7863:2015; determination of the content of mobile forms of phosphorus and potassium in the soil – by Chirykov's methods according to DSTU 4115–2002; determination of the amount of absorbed bases in the soil – according to Kappen-Hilkovits [13].

Presentation of the material of research. Harvesting of the main crops, which occupy the largest cultivated areas under conditions of intensive agriculture and can potentially be siderates: winter wheat, spring barley, peas and winter rape, took place in different periods. Winter rapeseed was harvested at the earliest – July 14, peas – 9 days later – July 23, winter wheat – July 29, and spring barley at the latest – August 6. In general, the period of harvesting crops, which can potentially be used as siderates, stretched for 23 days – from July 14 to August 6 (Table 1).

Table 1

Growth and development of sidereal crops, average 2019–2021, M±m

Siderate	Calendar date crop harvesting	Duration of the period from collection culture to the steps of its pedicle, days	Vegetation duration siderates to their earnings, days	The phase in which siderate vegetation has stopped
winter wheat	29.07. ±3	20±3	74±3	brushing
hot barley	06.08. ±3	23±3	63±3	bushing – exit to the tube
pea	23.07. ±3	25±3	75±3	budding
winter rape	14.07. ±3	18±3	91±3	the beginning of flowering

When crops are harvested, their grain and seeds are lost during threshing or even before harvesting when the seeds are spilled, the beans and pods are cracked, which can potentially lead to their germination, given the required soil moisture. Of course, different weather conditions can occur after harvesting, so the germination of carrion depends on the moisture of the soil and will require wrapping the lost seeds in the soil. Therefore, immediately after harvesting the main crops, the stubble was peeled.

The appearance of seedlings of fallow seeds began at different calendar times, as well as after a certain period of time after harvesting. According to calendar terms, the earliest sprouts of winter rapeseed appeared on August 1, and the latest of spring barley – on August 29. Seedlings of winter wheat and peas appeared almost simultaneously – on August 17–18.

In general, the period from harvesting to the appearance of sprouts of dead crops was the shortest for winter rapeseed – 18 days, and the longest for peas – 25 days. This is explained by the fact that winter rapeseed seeds are small and require much less moisture for germination than pea seeds, which, even before that, are buried much deeper in the soil, where there is not always moisture after summer rains.

Vegetation of carrion siderates lasted until November 1. After this period, the sowing was discus to earn vegetative mass. In general, all studied siderates vegetated for 63–91 days. Spring barley had the shortest vegetation period, but due to the fact that it is a spring grain crop with a short period of vernalization, during this time part of the plants reached the phase of emergence into the tube, and part remained in the tillering phase.

Winter wheat plants vegetated 11 days longer – for 74 days. However, winter wheat has a long period of vernalization, so its vegetation stopped in the tillering phase. Peas had a growing season of 75 days until the time of its disking. During this time, it reached the budding phase. The longest growing season of winter rapeseed was 91 days. During this time, it reached the phase of the beginning of flowering.

Since sidereal crops were grown from lost seeds and grains during harvesting, their density per unit area was uneven and not the same. The analysis of the density of the studied plants showed that the greatest losses and, accordingly, the greatest density were characteristic of winter rapeseed – 39 pcs./m2. The lowest density among the investigated siderates was characteristic of winter wheat – 18 pcs./m^2 (Table 2).

Table 2

Formed biological mass of sideral crops, average 2019–2021, M±m

Siderate	Plant density, pcs./$м^2$	Height for the period of earnings, cm	Above-ground and underground mass of siderates, t/ha
Winter wheat	18±4	22±4	23,1±0,03
Hot barley	26±5	28±3	23,5±0,03
Pea	31±4	49±3	29,8±0,02
Winter rape	39±5	64±5	33,0±0,03
HIP_{05}	1	7,3	0,3

Among the side crops before mowing, the highest were winter rapeseed plants – 64 cm, which were in the beginning of flowering at the time of mowing, and the lowest – winter wheat plants – 22 cm, which remained in the bushing phase, and spring barley – 28 cm, which were in phase of the beginning of exit into the tube. The pea plants were in the budding phase and had an appropriate height of 49 cm.

The density and height indicators of carrion siderates had a direct influence on the biological mass of the above-ground and underground parts of plants formed by them. In particular, the largest biological mass was formed by siderates of winter rape – 33.0 t/ha. The biological mass of peas was 9.6 % less than that of winter rape and amounted to 29.8 t/ha. The biological mass of winter wheat and spring barley was approximately the same – 23.1–23.5 t/ha, which was 28.8–30.0 % less than the above-ground and underground mass of winter rape.

So, among the investigated carrion siderates, the largest biological mass is formed by winter rape, which is determined by the greatest height and density of plants, the longest duration of vegetation of this type of sideral culture and the late phase of growth and development of winter rape, compared to other investigated types of siderates.

Close correlation-regression relationships were found among the investigated values. In particular, a strong positive correlation r = 0.813 was found between the duration of the growing season and the height of sideral crops before they were buried in the soil.

The coefficient of determination R2 = 0.66 shows that the height of siderate plants depends on the duration of vegetation by 66 %.

A strong positive correlation r = 0.838 was established between the duration of vegetation of siderates and their biological mass.

The coefficient of determination R2 = 0.70 shows that the biological mass of siderates depends on the height of the plants by 70 %.

A strong positive correlation r = 0.932 was established between the density of siderates and their biological mass.

The coefficient of determination R2 = 0.868 shows that the biological mass of siderates depends on plant density by 87 %.

A strong positive correlation r = 0.994 was established between the height of siderate plants and their vegetative mass.

The coefficient of determination R2 = 0.988 shows that the productivity of siderates depends on the height of the plants by 99 %.

Analysis of the results of laboratory research on the content of chemicals in the vegetative mass of siderates of winter wheat at the time of its cultivation into the soil contained 0.71 g/kg of phosphorus, 4.1 g/kg of potassium, 1.01 g/kg of calcium, 0.21 g/kg of magnesium and 0.52 g/kg of sodium. The content of phosphorus, potassium, calcium, magnesium and sodium in 1 kg of vegetative mass of spring barley was 0.65 g, 3.1 g, 1.14 g, 0.34 g and 0.18 g, respectively, of winter rapeseed – 0, 11 g, 4.4 g, 2.8 g, 0.62 g and 0.23 g and peas – 1.25 g, 4.8 g, 3.1 g, 0.75 g and 0.27 g. It should also be noted that the highest amount of phosphorus, potassium, calcium and magnesium in 1 kg of vegetative mass was observed in pea plants, and sodium in winter wheat. 1 kg of vegetative mass of peas contained the most nitrogen – 6.1 g, and spring barley plants – the least – 4.5 g (Table 3).

Table 3

The content of the main trace elements in the vegetative mass of siderates, g/kg, M±m

Siderate	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sodium
Winter wheat	4,8±0,12	0,71±0,02	4,1±0,07	1,01±0,06	0,21±0,03	0,52±0,01
Hot barley	4,5±0,41	0,65±0,04	3,1±0,03	1,14±0,02	0,34±0,09	0,18±0,04
Pea	6,1±0,31	1,25±0,04	4,8±0,08	3,1±0,07	0,75±0,08	0,27±0,08
Winter rape	5,4±0,33	1,11±0,03	4,4±0,08	2,8±0,05	0,62±0,04	0,23±0,07

Among microelements, the vegetative mass of siderates contained the most iron – 44–48 mg/kg. The largest amount is in spring barley plants, and the least amount is in pea plants (Table 4).

Table 4

The content of the main trace elements in the vegetative mass of siderates, mg/kg, M±m

Siderate	Iron	Copper	Zinc	Manganese	Cobalt
Winter wheat	46±2	0,80±0,03	7,8±1,2	7,2±1,2	0,22±0,04
Hot barley	48±3	0,45±0,02	3,2±1,0	4,3±1,2	0,06±0,01
Pea	44±2	0,70±0,05	4,3±1,1	5,5±1,1	0,02±0,01
Winter rape	45±1	0,68±0,03	4,4±1,1	5,1±1,1	0,02±0,01

Copper in the investigated siderates contained 0.45–0.80 mg/kg, the most in winter wheat plants, and the least in spring barley. The zinc content was the highest in winter wheat plants – 7.8 mg/kg, and the lowest – in spring barley plants – 3.2 mg/kg. Manganese was contained in siderates of 4.3–7.2 mg/kg. The most manganese was in winter wheat plants, and the least in spring barley. The most cobalt was contained in winter wheat plants – 0.22 mg/kg, and the least – in winter pea and rapeseed plants – 0.02 mg/kg.

The use of carrion 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 hydrolyzed 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 in 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 5). In terms of humus content, all studied variants were in the range of “average content” (2.1–3.0 %).

Table 5

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

Agrochemical parameters of the soil	Siderate				
	Winter wheat	**hot barley**	**pea**	**winter rape**	**without siderate**
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 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).

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 rapeseed, and the least – after the cultivation of spring barley. In general, the highest pH value of the reaction of the soil solution in 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 variant with siderate cultivation of winter rapeseed had a slightly acidic reaction (5.10–5.55 pH), the other variants 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 studies 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 for 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 coefficient of determination R2 = 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 coefficient of determination R2 = 0.968 shows that the increase in the content of exchangeable potassium in the soil depends on the yield of siderates by 97 %.

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 6).

Table 6

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	Siderate				
		Winter wheat	Hot barley	Pea	Winter rape	Without siderate
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 siderats 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 siderates, the hazard ratio was slightly lower and amounted to 0.18.

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 version without growing siderates – 0.26.

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 for the option without growing siderates was the lowest and was 0.14.

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.

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

$$Z_c = (K_{c1} + K_{c2} + K_{c3} + K_{c4}) - (n - 1),$$

where Z_c – total indicator of soil pollution; K_c – heavy metal hazard ratio; n – the amount of heavy metals considered.

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.

All studied siderates provided very low values of the total index 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 – by the siderates of winter wheat and spring barley – minus 2.21 each. In the option without growing siderates, the total indicator of soil contamination with several heavy metals was even lower – minus 2.37.

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 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.

Conclusions and proposals. Among the researched crops of intensive agriculture, which can potentially be suitable for obtaining dead sideral mass, winter rapeseed has the longest growing season for the formation of siderates – 91 days. This is determined by its early harvesting – mid-July, the shortest period among other crops from harvesting the crop to the emergence of its carcass seedlings – 18 days, which allows winter rapeseed plants to reach the phase of the beginning of flowering.

Spring barley has the shortest vegetation period of fallow siderates – 63 days. This is explained by its late harvesting – the first decade of August, the long period of sprouting from harvesting – 23 days, and the biological features of the long period of vernalization, which does not allow the bushing phase to pass quickly.

The largest biological mass of the above-ground and underground parts of carrion siderates is formed by winter rape – 33.0 t/ha. This is due to its greatest losses during harvesting and, accordingly, the greatest density – 39 pcs./m2 and the height of plants during the harvest period – 64 cm.

The smallest biological mass was formed by winter wheat and spring barley carcass siderates – 23.1–23.5 t/ha due to their insignificant density – 18–26 pcs./m2 and plant height at the time of their harvest – 22–28 cm.

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 influence 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. Didur I., Bakhmat M., Chynchyk O., Pantsyreva H., Telekalo N., Tkachuk O. Substantiation of agroecological factors on soybean agrophytocenoses by analysis of variance of the Right-Bank Forest-Steppe in Ukraine. *Ukrainian Journal of Ecology*. 2020. № 10 (5). P. 54–61.
2. Didur I., Chynchyk O., Pantsyreva H., Olifirovych S., Olifirovych V., Tkachuk O. Effect of fertilizers for Phaseolus vulgaris L. productivity in Western Forest-Steppe of Ukraine. *Ukrainian Journal of Ecology*. 2021. № 11 (1). P. 419–424. DOI: 10.15421/2021_61.
3. Honcharuk I., Pantsyreva H., Mazur V., Didur I., Tkachuk O., Telekalo N. Integration of traditional and innovation processes of development of modern science. Tkachuk O., Telekalo N. Agroecological potential of legumes in conditions of intensive agriculture of Ukraine. Collective monograph. Riga, Latvia : Baltija publishing, 2020. P. 42–108, 91–104.
4. Mazur V., Tkachuk O., Pantsyreva H., Demchuk O. Quality of pea seeds and agroecological condition of soil when using structured water. *Scientific Horizons*. 2021. Vol. 24 (7). P. 53–60.
5. Tkachuk O., Mordvanyuk M. 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 : Baltija publishing, 2022. P. 109–125.
6. Tkachuk O., Mordvaniuk M. 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, 2021. P. 221–240.
7. Tkachuk O., Alieksieiev O. Influence of siderates on the agro-ecological condition of the soil. Agro-ecological potential of soil cover of Vinnytsia region : Scientific monograph. Riga, Latvia : Baltija publishing, 2023. P. 189–211.
8. Razanov S.F. Effect of bean perennial plants growing on soil heavy metal concentrations. *Ukrainian Journal of Ecology*. 2018. № 8 (2). P. 294–300. DOI: 10.15421/2018_341.
9. Razanov S.F., Tkachuk O.P., Bakhmat O.M., Razanova A.M. Reducing danger of heavy metals accumulation in winter wheat grain which is grown after leguminous perennial precursor. *Ukrainian Journal of Ecology*. 2020. № 10 (1). P. 254–260. DOI: 10.15421/2020_40.
10. Razanov S.F., Tkachuk O.P., Ovcharuk V.V., Ovcharuk I.I. The effect of siderates on soil fertility. *Balanced environmental management*. 2021. №. 4. P. 144–152.

11. Razanov S.F., Tkachuk O.P., Razanova A.M., Bakhmat M.I., Bakhmat O.M. Intensity of heavy metal accumulation in plants of Silybum marianum L. in conditions of field rotation. *Ukrainian Journal of Ecology*. 2020. № 10 (2). P. 131–136. DOI: 10.15421/2020_75.

12. Tkachuk O.P., Didur I.M., Mazur O.V. Adaptability and agroecological sustainability of fast ripening soybean varieties. *Scientific reports of NUBiP.* 2023. № 1/101. URL: http://journals.nubip.edu.ua/index.php/Dopovidi/article/view/27349

13. Tkachuk O.P., Didur I.M., Mazur O.V. Adaptability, sustainability and productivity of mid-early soybean varieties. *Agrarian innovations*. 2022. № 16. P. 70–79.

14. Tkachuk O., Verhelis V. Intensity of soil pollution by toxic substances depending on the degree of its washout. *Scientific Horizons*. 2021. Vol. 24. № 3. P. 52–57.

15. Tkachuk O.P. Prerequisites for the transition of agriculture in Ukraine to ecologically balanced principles. *Environmental sciences*. 2022. №. 5 (44). P. 144–149.

16. Tkachuk O.P., Vradiy O.I. The balance of nutrients in the soil during the cultivation of leguminous crops. *Environmental sciences*. 2022. № 2 (41). P. 43–47.

17. Tkachuk O. Biological features of the distribution of root systems of perennial legume grasses in the context of climate change. *Scientific Horizons*. 2021. Vol. 24. № 2. P. 70–76.

18. Mazur V., Tkachuk O., Pantsyreva H., Kupchuk I., Mordvaniuk M., Chynchyk O. Ecological suitability peas (*Pisum sativum*) varieties to climate change in Ukraine. *Agraarteadus. Journal of Agricultural Science*. 2021. № 2. Vol. XXXII. P. 276–283.

19. Mazur V., Didur I., Tkachuk O., Pantsyreva H., Ovcharuk V. Agroecological stability of cultivars of sparsely distributed legumes in the context of climate change. *Scientific Horizons*, 2021. Vol. 24. №. 1. P. 54–60.

УДК 631.559:635.55:631.5(477.7)
DOI https://doi.org/10.32782/2226-0099.2023.132.27

УРОЖАЙНІСТЬ ЦИКОРІЮ САЛАТНОГО ЕНДИВІЙ ЗАЛЕЖНО ВІД СТРОКІВ ВИРОЩУВАННЯ В УМОВАХ ПІВДЕННОГО СТЕПУ УКРАЇНИ

Улянич О.І. *– д.с.-г.н., професор, член-кореспондент*
Національної академії аграрних наук України,
професор кафедри овочівництва,
Уманський національний університет садівництва
Шевчук К.М. *– к.с.-г.н.,*
докторант кафедри овочівництва,
Уманський національний університет садівництва

Стаття присвячена актуальним питанням удосконалення технології вирощування цикорію салатного ендивій у Південному Степу України. Дослідженнями передбачалося визначити оптимальний строк сівби цикорію салатного ендивій у відкритому ґрунті залежно від сорту, з'ясувати вплив на урожайність рослини. Застосовували у дослідженні загальнонаукові, вимірювальні, вагові, статистичні методи. Вивчення строку сівби цикорію салатного досліджували загальноприйнятими методами, зокрема звертаючи найбільшу увагу на фенологічні і біометричні показники росту і розвитку рослин, облік врожайності. У процесі узагальнення інформації проаналізовано джерела наукової літератури щодо строку сівби салату цикорного ендивій. Узагальнено ефективність