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SIDERATES AS AN ALTERNATIVE FOR RESTORATION OF SOIL FERTILITY ELEMENTS IN CONDITIONS OF CLIMATE WARMING IN THE RIGHT BANK FOREST STEPPE OF UKRAINE

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This scientific publication presents the results of research on the impact of different options for mineral fertilization on the formation of crop mass of crops such as peas, white mustard and oil radish. It also considers the issue of restoring the fertility elements of podzolized chernozem through the incorporation of the grown green mass of the listed crops into the soil in the context of climate change in the conditions of the Right-Bank Forest-Steppe.

The soil and climatic conditions of the Vinnytsia region are optimal for growing major agricultural crops, including crops that can be grown as green manure, namely: peas, white mustard, and oilseed radish.

Accordingly, as a result of our research, it was found that the highest green mass gains were observed in oilseed radish crops. The 2020 growing season provided the best conditions for the formation of the productivity of sideral crops, while 2019 gave the lowest indicators in the norm of N35 and the combination of potassium and phosphorus fertilizers $P_{35}K_{35}$ was similar for white mustard (4.5 t/ha and 3.3 t/ha, respectively), oilseed radish (4.8 t/ha and 3.7 t/ha, respectively) and peas (4.2 t/ha and 5.8 t/ha, respectively). The maximum increase in green mass over three years was observed when applying a double dose of nitrogen fertilizers on a phosphorus-potassium background $N_{70}P_{35}K_{35}$: for white mustard – 15.1 t/ha, for oil radish – 14.5 t/ha, for peas – 10.3 t/ha.

The dry matter content in the grown crop products depended on the type of crop and applied mineral fertilizers, varying from 16.3% to 29.3%, and in root residues – from 20.5% to 33.1%. With an increase in the dose of mineral fertilizers, the total yield of dry matter increased, but the share of its content in the biomass decreased. This confirms the direct relationship between the dose of fertilizers and the yield of dry matter (R^2 = 0.77-0.89), as well as the inverse relationship regarding the content in the green mass (R^2 = -0.54-0.79) and in the underground part (R^2 = -0.48-0.85). It was found that the application of different doses and types of mineral fertilizers did not have a significant effect on the humus content in the soil. At the same time, the cultivation of sideral crops and, accordingly, the plowing of green fertilizers. contributed to the movement of calcium from the lower layers of the soil to the arable, which reduced the active acidity of the soil and other indicators of the fertility of podzolized chernozem.

Key words: *green manure, mineral fertilizer, productivity, fertility elements, podzolized chernozem.*

Поліщук М.І. Сидерати як альтернатива відновлення елементів родючості грунтів в умовах потепління клімату Правобережного Лісостепу України

У даній науковій публікації викладено результати досліджень щодо впливу різних варіантів мінерального удобрення на формування рослинницької маси сільськогосподарських культур, таких як горох, біла гірчиця та олійна редька. Також розглядається питання відновлення елементів родючості чорнозему опідзоленого завдяки заробці вирощеної зеленої маси перерахованих культур в ґрунт у контексті зміни клімату в умовах Правобережного Лісостепу.

Ґрунтово-кліматичні умови Вінниччини є оптимальними для вирощування основних сільськогосподарських культур, в тому числі і культур які можна вирощувати як сидерати, а саме таких як: горох, гірчиця біла та редька олійна.

Відповідно в результаті проведених нами досліджень встановлено, що найвищі прирости зеленої маси спостерігалися на посівах редьки олійної. Вегетаційний період 2020 року *забезпечив найкращі умови для формування продуктивності сидеральних культур, у той час як 2019 рік дав найменші показники в нормі N_{35} та комбінації калійних і фосфорних добрив $P_{35}K_{35}$ був подібним для білої гірчиці (4,5 т/га та 3,3 т/га відповідно), олійної редьки (4,8 т/га та 3,7 т/га відповідно) і гороху (4,2 т/га та 5,8 т/га відповідно). Максимальний приріст зеленої маси протягом трьох років спостерігався при внесенні подвійної дози азотних добрив на фосфорно-калійному фоні $N_{70}P_{35}K_{35}$: для гірчиці білої – 15,1 т/га, для редьки олійної – 14,5 т/га, для гороху – 10,3 т/га.*

Вміст сухої речовини у вирощеній рослинницькій продукції залежав від виду культури та внесених мінеральних добрив, варіюючи від 16,3% до 29,3%, а в кореневих залишках – від 20,5% до 33,1%. При збільшенні дози мінеральних добрив загальний вихід сухої речовини зростав, однак частка її вмісту в біомасі зменшувалася. Це підтверджує прямий зв'язок між дозою добрив та виходом сухої речовини (R^2 = 0,77-0,89), а також зворотний зв'язок щодо вмісту в зеленої маси (R^2 = -0,54-0,79) і в підземній частині (R^2 = -0,48-0,85). Було виявлено, що внесення різних доз і типів мінеральних добрив не мало значного впливу на вміст гумусу в ґрунті. Водночас, вирощування сидеральних культур і відповідно заорювання зелених добрив. сприяло переміщенню кальцію з нижніх шарів ґрунту до орного, що знижувало активну кислотність ґрунту а також інші показники родючості чорнозему опідзоленого.

Ключові слова: *сидерати, мінеральне удобрення, продуктивність, елементи родючості, чорнозем опідзолений.*

Statement of the problem. In the context of unstable moisture in the Right-Bank Forest-Steppe and climate change caused by global warming and the shift of the transition from Forest-Steppe to Steppe [2, 9], the use of intercrops is limited. Therefore, it is reasonable to use green manure pairs for additional organic matter in the soil.

It should be noted that stabilising and improving soil fertility using traditional sources, such as manure and mineral fertilisers, is currently of limited effectiveness [6, 8]. This leads to the need to consider alternative, less costly sources that can be just as effective as manure. From a scientifically based approach, the use of green manure is advisable [8].

It is important to note that more convincing evidence of green manure effectiveness can be obtained by studying their response to mineral fertilisers, especially nitrogen fertilisers. Many issues related to the use of green manure on chernozem soils and its impact on agronomic characteristics, in particular the nitrogen regime, remain insufficiently understood in conditions of limited moisture. As a result of the irrational use of land in the past, the lack of a sustainable agricultural policy, crop rotation, and the excessive prevalence of cereals over fodder crops, biodiversity has become less diverse, and the ratio of arable land to fodder land has significantly decreased in favour of arable farming (1:0.2, instead of 1:1.6). In 1990, 45% of Ukraine's cropland was allocated to cereals, 12% to industrial crops, 6% to potatoes and vegetables and melons, while 37% was allocated to fodder crops. In 2012, cereals already occupied 55% of the area, industrial crops 29%, potatoes and melons 7%, while fodder crops decreased fourfold to 9%. It should be emphasised that the structure of winter wheat acreage requires green manure pairs at the level of 17-18% [2].

he projected depletion of global phosphorus reserves within 50-125 years can be partially postponed or reduced, as the root system of green manure crops such as sweet clover, mustard and others can take up hard-to-reach phosphate, calcium and magnesium from deep soil layers and transfer them to the surface. After decomposition and mineralisation, these elements become available for subsequent crops. On average, deep soil can supply approximately 20-25 kg/ha of P_2O_5, 100 kg/ha of CaO and 20 kg/ha of MgO. In addition, some of the organic matter in the soil is subject to mineralisation, and the law of agriculture requires that it be restored. However, this law is often violated, which leads to gradual soil degradation and causes serious concern [1].

In the context of economic instability in the agricultural sector, it is important to preserve soil fertility by implementing agrotechnological measures that do not lead to significant losses. One of these measures, especially in the Forest-Steppe zone, is the use of green manure pairs. The diversity and specificity of green manure requires theoretical and technological justification of their cultivation and fertilisation in order to reduce the negative impact on the environment and increase the productivity of crop rotations with the reproduction of organic soil components [8].

Studies on the suitability of various crops as green manure (peas, fodder beans, lupine, mustard and mixtures of fodder beans with peas) were first conducted at the Ivanovo Experimental Station (now the Ivanovo Experimental Breeding Station of the Institute of Bioenergy Crops and Sugar Beet of the National Academy of Sciences of Ukraine) [6, 7, 8].

The incorporation of special crops whose above-ground mass is partially or fully incorporated into the soil is called 'green manure', and the crop itself is called green manure. Under green manure, we should understand the incorporation of not only the aboveground mass but also the root system of the crop into the topsoil, i.e. the entire plant biomass. Ploughing the aboveground mass together with the root system of the plant better reflects the essence of green manure [6, 7].

The terms 'green fertiliser' and 'green manure' used for cover crops are interpreted in the same way in Ukrainian and English-language scientific literature. The American Soil Association defines 'green manure' as plant material that is applied to the soil in the green or mature phase to improve soil conditions. The term 'green manure', like 'green manure', is agreen fertiliser' is a conventional name; the first term reflects the role of sunlight (sidereus, referring to the heavenly bodies), and the second – the role of chlorophyll-bearing green organs of plants.

In order to restore depleted soils and increase their fertility, a rest period is required, during which the soil is left without cultivation or sown with a crop that reduces or weakens the soil stress process [1]. After sunflower cultivation in steppe areas, it is recommended to use mainly pure fallow, while in forest-steppe areas it is recommended to use spring crops that are vapour-intensive. Green manure fallow, where fallow crops are grown for use as green manure, is also an important type of cropping [3]. Cover crops add biodiversity to the farming system and contribute to the recycling of nutrients such as nitrogen, phosphorus, potassium, calcium, manganese and sulphur that are accumulated by green manure during the growing season. The use of different crops as green manure is determined by their biological characteristics and their impact on the soil. For example, legumes are used to increase the nitrogen content of the soil, while cabbage crops help improve the structural condition of the root layer and increase the mobility of phosphorus compounds. The impact of green manure on potential soil fertility mainly depends on the amount of biomass it is incorporated into the soil [7, 8]. It is important to note that green manure crops are highly effective when used in conjunction with mineral fertilisers. For example, the application of $N_{120}P_{120}K_{120}$ with sufficient soil moisture provides an increase of 0.49 t/ha of green mass of green manure per day. In dry years, this figure can be reduced by 10-18%.

Based on long-term studies, the final data show that after growing legume green manure, approximately 6.4-8.0 t/ha of dry matter, 60-100 kg/ha of nitrogen, 40-60 kg/ha of P_2O_5, 40-60 kg/ha of K_2O, 100-120 kg/ha of CaO and 40 kg/ha of MgO are applied to the root layer of the soil, while after cabbage green manure, approximately 4.0-5.2 t/ha of dry matter, 40-60 kg/ha of nitrogen are applied, 40-45 kg/ha P_2O_5, 30-40 kg/ha K_2O, 40-60 kg/ha CaO and 20-30 kg/ha MgO [8].

In general, the use of green manure under conditions of acute shortage of organic fertilisers can improve the balance of organic matter in the soil, stabilise its humus condition, increase the capacity of the nutrient balance and improve the physical, chemical and biological properties of the root layer.

Relevance of the topic. In situations where there is a shortage of organic fertilisers, the use of green manure crops makes it possible to improve the balance of organic matter in the soil, stabilise its humus state, increase the ability to retain the necessary nutrients and improve the physical, chemical and biological characteristics of the root layer. However, there are still a number of unresolved issues, such as the choice of the best crop to grow and the optimal way to fertilise it. This problem is especially relevant for the Right-Bank Forest-Steppe of Ukraine, where green manure pairs were not used before due to high production levels and sufficient organic fertiliser application. Our research is aimed at addressing these issues.

Given the current global climate change that is affecting agricultural production, it is important to address the challenges of protecting soil fertility and increasing the productivity and sustainability of agrophytocenoses, taking into account the soil and climatic characteristics of the zone. This can be achieved through comprehensive adaptive landscape farming measures, which, along with restoring fertility and protecting against erosion, ensure the preservation of agricultural landscapes and environmental safety for people. Therefore, it is important to develop and implement a green manure farming system in the country's modern agriculture [8].

Objective of the research. The purpose of our research is to determine the effectiveness of different types of green manure crops and different doses of fertilizers for them on the podzolic black soil of the Right-Bank Forest-Steppe.

Summary of the main material. The research was conducted during 2019-2021 at the Uladovo-Lyulynetska experimental breeding station of the Institute of Bioenergy Crops and Sugar Beet of the National Academy of Sciences of Ukraine, located in the Kalynivka district of Vinnytsia region. The territory of the station is characterised by the following soil types: typical chernozems, podzolised and leached chernozems formed on loess and loess-like deposits. The majority of the region has soil-forming rocks that are relatively close to the surface and are often covered with fluvioglacial sands [7, 8].

The climate of the plant area is moderately warm and humid. The hydrothermal coefficient (HTC) is 1.5-1.8. The average daily air temperature rises above +5°C between 6 and 10 April, while in late October and early November the average daily air temperature drops below +5˚C. The first frosts on the soil surface are observed in the last decade of September, and in the air – in the first decade of October. In early May, the last frosts are observed on the soil surface and in the air in the third decade of April.

During the years of research, the weather conditions on the territory of the Uladovo-Lyulynets Experimental Breeding Station were dry. At the same time, the average monthly temperature during the growing season increased by 0.8-3.8°C, and there was a decrease in the total amount of precipitation during the growing season compared to the long-term average.

Research methodology. The experimental part of the work on studying the effectiveness of applying different doses and types of mineral fertilisers under green manure pairs was carried out in a short-term experiment. Crops were sown as normal for green manure: peas – 300 kg/ha, white mustard – 20 kg/ha, oil radish – 20 kg/ha. The control was pure steam. Each crop was fertilised as follows: 1) no fertiliser – control; 2) N_{35}; 3) $P_{35}K_{35}$; 4) $N_{35}K_{35}$; 5) $N_{35}P_{35}$; 6) $N_{35}P_{35}K_{35}$; 7) $N_{70}P_{35}K_{35}$.

The sown area of the experimental plot is 36 m^2 (3.6 m x 10 m), the accounting area is 25 m^2 (2.5 m x 10 m). The plots were arranged in a sequential arrangement, and the experiments were replicated three times.

Sowing of green manure was carried out in early April-mid-May, depending on the species characteristics of the studied crops – by the usual in-line method with a SZT-3.6 seeder. The predecessor was winter wheat. Before sowing, the seeds of cabbage crops were treated with Cruiser 350 FS against black flea beetle at a rate of 4 l/t. To control weeds, pre-emergence herbicide was applied after sowing the crop.

At the onset of the flowering phase and the beginning of the formation of pea beans and pods in cabbage crops, green manure was mowed in the second decade of June and the first decade of July using a MR 2.7 mulcher. The green mass was harvested with a PLN-4-35 plough to a depth of 25-27 cm. During summer and early autumn, the soil was kept in a state of semi-steam.

In accordance with the research programme, the following measurements and analyses were carried out in the mass analysis laboratory: – determination of the content of nitrate (N-NO $^{3-}$) and ammonium nitrogen (N-NH $^{4+}$) in the soil in accordance with DSTU 4729; – measurement of the amount of mobile phosphorus and potassium compounds in the soil by the Chirikov method in accordance with DSTU 4115; Determination of the pH of aqueous suspension in accordance with DSTU ISO 10390; Estimation of the content of total humus in accordance with DSTU 4289; to determine the elements of green manure plant productivity, generally accepted methods were used [9].

To process the data obtained, the method of analysis of variance of a two-factor field experiment was used using the Microsoft Excel 2003 standard software package.

Results of experimental studies. Among all green manure crops, regardless of the fertiliser doses applied, white mustard showed the most impressive growth due to the characteristics of this biotype, while the lowest growth was observed in peas. The yield of green manure was largely dependent on weather conditions (Table 1). For example, in 2019 and 2020, a large amount of precipitation fell in May-June, 149 and 199 mm, respectively, which exceeded the average annual norm of 142 mm, and this led to an increase in green mass to 16.2-48.0 t/ha.

In 2021, after sowing white mustard, oil radish and peas, weather conditions deteriorated with a drop in air temperature and snowfall, which delayed the emergence of cabbage and peas by 20-25 days and reduced their productivity to 14.5-36.0 t/ha.

It is worth noting that the most stable on average over the years of research were the yields of pea phytomass. Also, during the study years, a shortened vegetation period was observed (the phenomenon of neoteny), which can be explained by the abrupt onset of warm weather (especially in 2020 and 2021).

Thus, weather conditions influenced the growth and development of plants, which, in turn, affected the accumulation of green manure phytomass and depended on both their biological characteristics and fertilisation.

As can be seen from the data in Table 1, the application of mineral fertilisers had a positive effect on the increase in green manure phytomass. For example, the increase in phytomass from the application of nitrogen fertiliser alone (N_{35}) and from the combined application of potassium and phosphorus fertiliser (P_{35}K35) was approximately the same for white mustard – 4.5 t/ha and 3.3 t/ha respectively, oil radish – 4.8 t/ha and 3.7 t/ha respectively, and peas – 4.2 t/ha and 5.8 t/ha respectively. While the combination of potash or phosphorus fertilisers with nitrogen fertilisers led to a significant increase in green mass accumulation. The best growth of green manure phytomass over three years was observed in the case of double dose of nitrogen fertilizers on a phosphorus-potassium background ($N_{70}P_{35}K_{35}$), namely: white mustard – 15.1 t/ha, oil radish – 14.5 t/ha, peas – 10.3 t/ha. It was found that the dry matter content in the phytomass depends on the type of crop and fertiliser application and ranges from 16.3% to 29.3%, and in root residues from 20.5% to 33.1%. However, some scientists have different opinions on this issue, offering different variants of the relationship between the dry matter content of the underground and aboveground parts of plants.

Table 1

Yield of phytomass of siderates before incorporation into the plant depending on fertiliser and crop

Experimental design		Year of research			Average for three years
Fertiliser (factor A)	Culture (factor B)	2019	2020	2021	
		Phytomass yield, t/ha			
No fertiliser (control)	Peas	17,7	29,5	20,0	22,4
	White mustard	30,5	24,0	15,0	23,2
	Oil radish	34,4	28,5	21,0	28,0
N_{35}	Peas	23,4	34,0	22,5	26,6
	White mustard	33,5	32,0	17,5	27,7
	Oil radish	36,5	36,5	25,5	32,8
$P_{35}K_{35}$	Peas	25,0	36,5	23,0	28,3
	White mustard	34,0	28,5	17,0	26,5
	Oil radish	36,2	31,5	27,5	31,7
$N_{35}K_{35}$	Peas	27,2	35,0	21,5	27,9
	White mustard	34,5	34,0	24,1	30,9
	Oil radish	37,9	38,0	22,0	32,6
$N_{35}P_{35}$	Peas	27,5	37,5	30,0	31,7
	White mustard	35,5	34,5	27,0	32,3
	Oil radish	42,3	39,0	24,5	35,3
$N_{35}P_{35}K_{35}$	Peas	30,0	38,5	26,5	31,7
	White mustard	38,4	35,5	28,0	34,0
	Oil radish	44,8	43,0	27,0	38,3
$N_{70}P_{35}K_{35}$	Peas	31,1	40,0	27,0	32,7
	White mustard	39,6	38,7	36,5	38,3
	Oil radish	47,5	48,5	31,5	42,5
HIP_{05}	*2019 r.*	*A – 1,76; B – 1,52; AB –4,02*			
	2020 r.	*A – 1,42; B – 1,20; AB –3,18*			
	2021 r.	*A – 1,08; B – 0,93; AB – 2,43*			

The average dry matter yield of green manure biomass depending on fertiliser for 2019-2021 is shown in Table 2.

On average, during the years of research, the highest growth of dry matter was obtained when growing oil radish on the background of $N_{70}P_{35}K_{35}$ – 1.89 t/ha or 22%, peas and white mustard on the background of $N_{35}P_{35}K_{35}$ – 2.61 t/ha, 3.23 t/ha, respectively, which is 29% and 35% more than in the control variant without fertilisation.

Thus, with an increase in the dose of fertiliser, the total dry matter yield increased, while the share of dry matter in biomass decreased. This indicates a direct correlation between the dose of mineral fertiliser application and dry matter yield (R^2 = 0.77-0.89, depending on the green manure), as well as an inverse correlation with the content in phytomass (R^2 = -0.54-0.79) and the underground part (R^2 = -0.48-0.85).

Table 2

Dry matter yield of green manure biomass of different crops (average for 2019-2021)

Experimental design		Siderata		
		Peas	White mustard	Oil radish
		dry matter yield, t/ha		
No fertiliser (control)		8,85	9,25	8,55
N_{35}		10,00	9,43	8,99
$P_{35}K_{35}$		10,84	10,18	9,06
$N_{35}K_{35}$		10,18	10,49	8,96
N_{35}P35		11,32	11,65	9,75
$N_{35}P_{35}K_{35}$		11,41	12,42	10,25
$N_{70}P_{35}K_{35}$		11,35	12,18	10,39
HIP_{05}	*2019 r.*	Factor A – 0,21; B – 0,18; AB – 0,48		
	2020 r.	Factor A – 0,19; B – 0,16; AB – 0,42		
	2021 r.	Factor A – 0,24; B – 0,20; AB – 0,54		

Studies have shown that fertilised green manure crops coincide in the amount of organic matter entering the soil with crops for which the application of 35 kg/ha of fertiliser corresponds to once every 5 years. This rate is scientifically justified for fields with podzolised black soil and is suitable for growing peas, with only nitrogen fertiliser at a dose of 35 kg/ha of fertiliser (Table 3).

Table 3

Manure equivalents in terms of dry organic matter in the soil with green manure biomass depending on their fertilisation (average for 2019-2021)

Experimental design	Siderata		
	Peas	White mustard	Oil radish
	dry matter yield, t/ha		
No fertiliser (control)	35	37	34
N_{35}	40	38	36
$P_{35}K_{35}$	43	41	36
$N_{35}K_{35}$	41	42	35
$N_{35}P_{35}$	45	46	39
$N_{35}P_{35}K_{35}$	45	49	41
$N_{70}P_{35}K_{35}$	45	49	41

Oil radish had a lower accumulation of dry matter and required the maximum dose of mineral fertiliser ($N_{70}P_{35}K_{35}$) to achieve an equivalent amount of organic matter.

The annual growth of fresh biomass in the soil at a depth of 0-30 cm in the amount of 35 t/ha, converted to dry matter, provides almost the same level of water-soluble humus content as on unaltered land.

Humus content is an important indicator of soil fertility. However, over the past 130 years, Ukraine has lost up to 25% of its humus, and this figure is expected to decline further.

It was found that the application of different doses and types of mineral fertilis green manure did not significantly affect the humus content of the soil (Table 4).

Table 4

The effect of green manure and its fertilisation on the humus content in the 0-40 cm soil layer in autumn (average 2019-2021)

Experimental design	Soil layer, cm	Siderata		
		Peas	White mustard	Oil radish
		dry matter yield, t/ha		
No fertiliser (control)	0-20	3,13	3,13	3,13
	20-40	3,08	3,08	3,08
N_{35}	0-20	3,13	3,13	3,13
	20-40	3,08	3,08	3,08
$P_{35}K_{35}$	0-20	3,14	3,14	3,14
	20-40	3,08	3,08	3,08
$N_{35}K_{35}$	0-20	3,13	3,13	3,13
	20-40	3,08	3,08	3,08
$N_{35}P_{35}$	0-20	3,14	3,14	3,14
	20-40	3,08	3,08	3,08
$N_{35}P_{35}K_{35}$	0-20	3,14	3,14	3,14
	20-40	3,08	3,08	3,08
$N_{70}P_{35}K_{35}$	0-20	3,14	3,14	3,14
	20-40	3,08	3,08	3,08

Under the conditions of clean fallow, a decrease in soil humus content was observed in both the arable and subsoil layers compared to green manure pairs. The obtained research results are confirmed by the data of other researchers [6, 8] and are explained by the fact that the organic matter of green manure is mineralised by 60-80% during the first year, converted into humus (10-30%), included in the biomass of microorganisms (3-8%) and remains unhumified in approximately the same amount.

Intensive agricultural use of arable land results in soil decalcification. This process is the beginning of soil degradation, which leads to acidification of the soil solution, loss of organic matter, deterioration of agrophysical parameters and microbiological activity of soils, as well as a reduction (up to 40%) in the efficiency of fertilisers and deterioration of product quality.

The systematic use of organic fertilisers is an effective measure to optimise the acid-base balance of the soil. The mechanism of their positive impact remains poorly understood and controversial, as their main function is to restore the organic part of the soil. Studies have shown that green manure has almost no effect on the acidity of chernozem soil solution due to its high buffering capacity.

Taking into account the above, the effect of mineral fertilisers applied under green manure on soil acidity was determined (Table 5).

Table 5

Effect of green manure fertilisation on active soil acidity in the 0-20 cm layer in autumn (pH water) (average for 2019-2021)

Experimental design	Pure steam	Siderata		
		Peas	White mustard	Oil radish
No fertiliser (control)	6,5	6,7	6,6	6,5
N_{35}	-	6,6	6,3	6,2
$P_{35}K_{35}$	-	6,8	6,6	6,4
$N_{35}K_{35}$	-	6,5	6,5	6,2
$N_{35}P_{35}$	-	6,7	6,4	6,3
$N_{35}P_{35}K_{35}$	-	6,7	6,3	6,2
$N_{70}P_{35}K_{35}$	-	6,6	6,4	6,3

It was found that the value of active soil acidity (pH of aqueous suspension) in the layer 0-20 cm after different fallow in the variant without fertilisation ranged from 6.5-6.9, as well as in the pure fallow – 6.5.

During the three years of research, after the application of mineral fertilisers under green manure, the pH level of the soil aqueous solution at the time of sowing winter wheat varied from 6.2 to 7.0, depending on the specific variant of the experiment. This means that the introduction of green manure into the soil helped to neutralise the negative impact of physiologically acidic mineral fertilisers. A particular difference in the pH of the soil aqueous solution was found when mineral fertilisers were applied under green manure with oil radish.

The decrease in active acidity of the soil after growing siderates is explained by the movement of calcium from the lower layers by the root system of plants to the arable layer of the soil. Correlation analysis showed that there is a weak relationship between the pH value of the soil aqueous solution and the input of calcium into the root layer together with the biomass of siderates for white mustard and oil radish (respectively, $R^2 = 0.25$; 0.20), and no relationship at all for peas ($R^2 = 0.02$).

One of the key indicators of the ecological condition and vital activity of the soil is its biological activity. An integral indicator of this activity is the amount of carbon dioxide emitted, which indicates the intensity of soil 'breathing' and the transformation of organic matter. The intensity of soil biological activity according to this indicator depends on soil type, moisture, temperature, organic matter and carbon to nitrogen ratio [6, 8].

It was found that the type of crop used as a green manure has the greatest impact on the intensity of soil respiration (Table 6).

In the control plots (without fertilizers), the highest release of $C–CO^2$ from the soil, regardless of fertilization, was recorded when growing green manure peas, and it was 545 mg/($m^2 \times h$). This is explained by the higher content of nitrogen compounds in the biomass of these plants compared to other studied crops, so most of the organic matter is consumed by microorganisms and mineralized more intensively.

Table 6

Effect of green manure fertilisation on C-CO2 emission from the soil two months after green manure production (average for 2019-2021

Fertiliser (factor A)	Green manure (factor B)		
	Peas	**White mustard**	**Oil radish**
	C-CO² emission from the soil, mg/(m² × h)		
No fertiliser (control)	545	514	500
N_{35}	572	540	526
$P_{35}K_{35}$	583	542	527
$N_{35}K_{35}$	591	557	532
$N_{35}P_{35}$	602	565	538
$N_{35}P_{35}K_{35}$	605	574	553
$N_{70}P_{35}K_{35}$	612	597	571

Note: Under pure steam – 271 C-CO2 mg/(m2 ×h).

The application of mineral fertilisers led to an increase in carbon dioxide (C-CO^2) emissions into the soil. The use of only nitrogen (N_{35}) or phosphorus and potassium fertilisers ($P_{35}K_{35}$) caused a similar increase in soil respiration after mustard, where it was 5-6%, and radish, where this figure was 5%.

The application of full mineral fertilisers ($N_{35}P_{35}K_{35}$) caused a significant increase in C-CO^2 emissions. The experiment with a double dose of nitrogen fertiliser on a phosphorus-potassium background ($N_{70}P_{35}K_{35}$) provided the highest carbon dioxide emissions during the decomposition of plant mass over three years on average: 16% for white mustard, 14% for oil radish and 12% for peas.

Compared to fertilised green manure, growing green manure on pure steam resulted in a 1.9-2.3-fold reduction in carbon dioxide emissions. This confirms the results of research by other scientists.

Thus, the application of mineral fertilisers under green manure increases carbon dioxide emissions, and the nitrogen component of total mineral fertiliser has the greatest impact on this indicator. Increasing the dose of nitrogen fertiliser to 70 kg/ha a.i. was effective for white mustard and oil radish. In pea cultivation, only $N_{35}P_{35}$ can be applied, which leads to an increase in C-CO^2 emissions by 10-11% compared to green manure without mineral fertilisers

Conclusions and prospects for further research. The application of mineral fertilisers had a positive effect on the increase of green manure phytomass. The growth of phytomass from the application of nitrogen fertilizers alone (N_{35}) and from the joint application of potassium and phosphorus fertilisers ($P_{35}K_{35}$) was approximately at the same level for white mustard – 4.5 t/ha and 3.3 t/ha respectively, oil radish – 4.8 t/ha and 3.7 t/ha respectively, peas – 4.2 t/ha and 5.8 t/ha respectively. The best increase in green manure phytomass over three years was observed in the case of double dose nitrogen fertilisation on a phosphorus-potassium background ($N_{70}P_{35}K_{35}$), namely: white mustard – 15.1 t/ha, oil radish – 14.5 t/ha, peas – 10.3 t/ha. The dry matter content in the phytomass depends on the type of crop and fertiliser application and ranges from 16.3% to 29.3%, and in root residues from 20.5% to 33.1%. With an increase in the fertiliser dose, the total dry matter yield increased, while the share of dry matter in biomass decreased. This indicates a direct correlation between the dose of mineral fertilisers and dry matter yield (R^2 = 0.77-0.89 depending on the green manure), as well as an inverse correlation with the content in phytomass (R^2 = -0.54-0.79) and underground part (R^2 = -0.48-0.85).

It was found that the application of different doses and types of mineral fertilisers under green manure did not significantly affect the humus content in the soil. Growing green manure leads to the movement of calcium from the lower layers to the topsoil, which leads to a decrease in the active acidity of the soil.

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