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The role of *Medicago sativa* L. in the ecologization of agricultural production

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ABSTRACT

The current study explores the role of alfalfa (*Medicago sativa* L.) as a valuable perennial legume crop that serves as an effective precursor in crop rotations for maize and winter wheat cultivated on grey forest soils in the Vinnytsia region of Ukraine. Alfalfa is recognized as one of the most productive and valuable forage crops, capable of addressing the deficit of plant-based protein in livestock feed across many regions. It is unmatched in terms of protein quality and essential amino acid content. However, key factors limiting its cultivation include the decline of the livestock sector, reliance on monotonous forage systems, and soil acidification, which reduces alfalfa's productivity, nutritional value, and longevity in grass stands. The study analyzes the agrobiological properties of alfalfa in improving soil structure, increasing organic matter content, and stimulating microbial activity. The results highlight its impact on enhancing soil fertility, improving the productivity of subsequent crops, and reducing the need for mineral fertilizers. The highest productivity of alfalfa stands was recorded under the second management regime – cutting at the early flowering stage. It was found that the early-maturing semi-dwarf winter wheat variety Bilotserkivska outperformed the mid-early Tsarivna variety by 0.27–0.54 t/ha regardless of sowing time. Among maize hybrids, Bilozirskyi 295 SV showed superior silage yield compared to Monika 350 MV across all fertilization levels. The highest yield (28.9 t/ha) was recorded in Bilozirskyi 295 SV at the wax ripeness stage with nitrogen application at N_{135}. As a rotation crop, alfalfa facilitates the development of stable and highly productive agroecosystems, reduces the need for mineral fertilizers and agrochemicals, and thereby increases the efficiency and environmental sustainability of farming. Under the conditions of climate change and resource conservation needs, the integration of alfalfa into crop rotations is a crucial direction for the sustainable development of agricultural production.

Keywords: alfalfa (*Medicago sativa* L.), maize, winter wheat, fertilization, precursor crop, biological factor, agricultural intensification, soil fertility

INTRODUCTION

Alfalfa (*Medicago sativa* L.) occupies a key place in the structure of perennial leguminous grasses, as its high protein value and ability to fix nitrogen symbiotically contribute to increased agricultural efficiency. According to FAO (2024), the area under alfalfa cultivation in Europe exceeds 5.0 million hectares, providing up to 20% of the feed protein volume (Hetman et al., 2025).

The use of alfalfa as a component of legume-grass mixtures of perennial forage crops ensures long-term and efficient utilization of grasslands for the production of high-quality hay or for grazing various types of livestock. Due to the formation of dense sod in agro-phytocoenoses, such mixtures prevent the degradation of plant cover and contribute to a significant increase in both aboveground and belowground biomass, which helps to prevent soil erosion on slopes (Tucak et al., 2021; Karbivska et al., 2022; Kurhak et al., 2023; Hetman et al., 2025). Thus, they serve as an effective means of protecting soil from wind and water erosion (Annicchiarico et al., 2011; Vozhehova et al., 2021; Tyshchenko et al., 2022).

Perennial leguminous grasses that are used for a long time should be considered a natural source of accumulation in the soil of about 10–12 t/ha of root and crop residues (Melnik, 2020; Olifirovych et al., 2023). After their decomposition, nitrogen reserves increase by 150–300 kg/ha, which becomes available to other crops in the crop rotation. The feasibility of growing perennial legumes as precursors when growing grain crops is confirmed by studies by Kvitka G.P. (2013), which indicate an increase in humus content and, in terms of efficiency, is equivalent to the application of 35–40 t/ha of organic fertilizers. The formation of humus from root residues begins mainly in the second year of the grass stand's life, when the intensity of mineralization processes decreases due to soil compaction under the plants (Kvitko et al., 2013).

According to research conducted by the V.M. Remeslo Myronivka Institute of Wheat, crop predecessors contribute 14% to the formation of wheat yield, ranking third after plant protection measures (27%) and fertilizers (17%) (Protopish et al., 2012; Protopish, 2014).

Long-term studies conducted by the Institute of Feed Research and Agriculture of Podillia of NAAS have confirmed the feasibility of coverless cultivation of alfalfa (*Medicago sativa* L.), which, over two years of stand use under favorable agro-ecological conditions, accumulates approximately 600 kg/ha of biological nitrogen in the soil (Kvitko et al., 1971). This allows for a 50–80% reduction in energy costs for the purchase and application of mineral nitrogen fertilizers for subsequent crops (Zabarnyi, 2011). Specifically, alfalfa is capable of assimilating phosphorus (P) from the soil through root exudates and interactions with arbuscular mycorrhizal fungi, which promotes an efficient process of symbiotic nitrogen fixation (N). Acting as an active microbiological hotspot, alfalfa possesses unique biological properties and significant economic advantages (Melnyk, 2020; Kurgak et al., 2023).

In addition to the aforementioned unique capabilities, alfalfa, with its well-developed and robust root system, is capable of accumulating approximately 10.8 t/ha of dry root biomass in the arable soil layer, containing (kg/ha): 55.1 – nitrogen (N), 13.8 – phosphorus (P_2O_5), and 21.9 – potassium (K_2O) (Barabash, 1998; Hetman et al., 2013; Petrychenko et al., 2020; Hetman et al., 2021). At the same time, soil bulk density decreases, total porosity and pore volume increase, which contributes to higher field water capacity and the share of water-stable aggregates in the arable layer (Malyarchuk et al., 2024). This enhances the agroecological and economic value of alfalfa in crop rotations for plant production regardless of the soil-climatic growing zone (Latrach et al., 2014; Tyshchenko et al., 2021; Vozhehova et al., 2023).

It has been established that the processes of restoration and maintenance of soil fertility are possible only under the condition of a scientifically sound crop structure, which includes the correct selection of crops and their rational placement in crop rotation (Antipova, 2008; Boiko et al., 2014; Olifirovych et al., 2023). Rational selection of crops in crop rotation, taking into account their biological properties, sowing and harvesting dates, as well as the application of appropriate care measures, contributes to reducing the anthropogenic load on the agroecosystem. Thus, in the left-bank Forest-Steppe, the gluten content in winter wheat grain was 26.2% when grown after black fallow, 25.7% after alfalfa (one cut), and 23.2% after silage corn (Predko, 1982).

Scientists from research institutions have proven the effectiveness of using meadow clover and alfalfa as the best predecessors for winter wheat in the forest-steppe zone when grown using resource-saving technology (Kutsenko et al., 2008).

Therefore, the use of alfalfa in intensifying agriculture is a promising direction for increasing crop production and protecting the environment, especially in the current conditions of climate change.

The aim of the research is to substantiate the agronomic significance of alfalfa as a precursor and biological factor that contributes to increasing soil fertility, enriching it with organic matter and nitrogen, and ensuring environmentally safe intensification of agriculture.

MATERIALS AND METHODS

The research was conducted during 2016–2020 at the Department of Field Forage Crops, Hayfields, and Pastures of the Institute of Feed Research and Agriculture of Podillia, NAAS of Ukraine. The experimental plots were located on grey podzolic medium loamy soil developed on loess deposits, which is typical of the Right-Bank Forest-Steppe zone and Vinnytsia region. The arable soil layer (0–30 cm) was characterized by the following agrochemical parameters: pH (H_2O) – 5.9; humus content (according to Tiurin) – 2.52%; alkaline hydrolyzable nitrogen (by Kornfild) – 97 mg/kg of soil; exchangeable potassium – 115 mg/kg; available phosphorus (by Chyrikov) – 90 mg/kg. The hydrolytic acidity was 3.40 meq/100 g of soil.

Hydrothermal conditions during the research period differed significantly from the long-term average, which manifested itself in uneven precipitation distribution and elevated temperatures during the growing season. In the year of sowing and grass formation (2016), the sum of active temperatures was 1235 °C, exceeding the norm by 244 °C, while precipitation was 26% below normal (only 106 mm), and the hydrothermal coefficient (HTC) was 0.86. In the second year of vegetation, the summer period was marked by an increase in the average daily temperature to 19.1–21.4 °C and a 1.8-fold decrease in precipitation compared to the long-term average. During the third and fourth years of alfalfa grass use (2018–2019), the average daily air temperatures in May–September were 15.4–20.0 °C in 2018 and 12.2–20.1 °C in 2019, while precipitation was 295 mm and 254 mm, respectively.

The alfalfa cultivation technology was generally accepted for the conditions of the Forest-Steppe, which involved liming the soil to neutralize acidity at the full rate according to hydrolytic acidity, and applying phosphorus-potassium fertilizers in the spring during pre-sowing cultivation as a "reserve."

The study examined the impact of three-year cultivation of *Medicago sativa* L. cv. Rosana as a preceding crop on the productivity of two winter wheat cultivars (the early-maturing Bilotserkivska semi-dwarf and the medium-early Tsarivna), as well as two silage maize hybrids (Bilozirskyi 295 SV and Monika 359 MV). Phenological observations and yield assessments were conducted according to generally accepted and widely tested methodological guidelines in forage production (Babych et al., 1998).

RESULTS AND DISCUSSION

The use of legumes as precursors contributes to improving soil structure and increasing soil fertility, which is a key factor for the successful cultivation of crops in crop rotations, in particular winter wheat and corn for grain or silage. Moreover, the positive effect after their cultivation lasts up to three years (Lykhochvor, 2004). Studies have shown that with three years of use of alfalfa harvested at the beginning of flowering, the average dry matter yield is 37.31 t/ha.

It has been established that the highest productivity of alfalfa grass was ensured by the following regime of use: mowing all crops at the beginning of flowering. The maximum crude protein yield (7.3 t/ha) was obtained precisely when mowing at the beginning of flowering, which exceeded the indicators for mowing all crops in the budding phase. At the same time, the protein content in plant raw materials was higher than in the first regime and amounted to 211 g (Table 1).

The highest exchange energy output – 103.70 GJ/ha – was recorded at the beginning of flowering, while during budding, this indicator was 91.30 GJ/ha. The calculations showed that the energy efficiency coefficient of Rosana alfalfa reached its highest values within the range of 3.24–3.62, depending on the mode of use of the grass stand.

Thanks to the effective use of alfalfa as a biological factor in crop production, two harvests can accumulate 196.27–217.72 GJ/ha of energy per unit area. After alfalfa, the PAR (photosynthetically active radiation) utilization coefficient for growing winter wheat for grain was 1.66–1.84%. Thus, sowing winter wheat in the first ten days of October after alfalfa, without the use of mineral fertilizers, provided an increase in grain yield by 0.18–0.45 t/ha compared to the traditional sowing period in September (Table 2).

The results show that later sowing (October 7) had a positive effect on the yield of the Bilotserkivska semi-dwarf variety, which increased from 5.16 t/ha (when sown on September 17) to 5.34 t/ha. The yield of the Tsarivna variety also increased – from 4.62 t/ha to 5.07 t/ha. This indicates the adaptability of both varieties to later sowing dates, especially in favorable agroclimatic conditions.

The PAR intake during the growing season was slightly higher with later sowing dates – for both varieties, the indicator increased by

Table 1. Forage productivity of alfalfa (*Medicago sativa* L.) cultivar Rosana depending on the utilization regimes

Indicator	Value
Regime 1: All cuts at the bud stage (BBCH code 50)	
Dry matter yield, t/ha	34.24
Crude protein yield, t/ha	7.23
Metabolic energy yield, GJ/ha	91.30
Dry matter content of crude protein, g	211
Regime 2: All cuts at the beginning of the flowering stage (BBCH code 60)	
Dry matter yield, t/ha	37.31
Crude protein yield, t/ha	7.30
Metabolic energy yield, GJ/ha	103.70
Crude protein content of dry matter, g	196

Table 2. PAR Utilization in winter wheat grown after alfalfa

Indicators	Sowing dates			
	17.09		07.10	
	Bilotserkivska semi-dwarf	Tsarivna	Bilotserkivska Semi-Dwarf	Tsarivna
Grain yield, t/ha	5.16	4,62	5.34	5.07
PAR input, GJ/ha	11570	11770	11870	11970
Accumulated energy in alfalfa and wheat yield, GJ/ha	212.37	196.27	217.72	209.68
PAR utilization efficiency, %	1.84	1.66	1.83	1.75

300–400 GJ/ha. Despite the slight difference in PAR intake, the accumulation of energy in the grain yield and related products also increased: for the Bilotserkivska semi-dwarf variety – from 212.37 to 217.72 GJ/ha, for the Tsarivna variety – from 196.27 to 209.68 GJ/ha. The PAR utilization coefficient (PUC), which is an important indicator of crop energy efficiency, was higher in the Bilotserkivska semi-dwarf variety at both sowing dates (1.84% and 1.83%, respectively), indicating its higher ability to convert solar energy into biomass. In the Tsarivna variety, the PAR utilization coefficient was 1.66% for early sowing and 1.75% for later sowing.

The results of the studies showed that the productivity of corn for silage in the milky-waxy ripeness phase of the grain with the use of nitrogen fertilizers was at the level of 19.9 to 25.3 t/ha, with an increase in the dose of nitrogen fertilizer, an increase in the productivity of both hybrids was observed (Figure 1).

For the Bilozirskyi 295 SV hybrid, dry matter yield at the milk-wax maturity stage increased from 22.1 t/ha at N_{45} to 24.7 t/ha at N_{135}, and at the wax maturity stage – from 25.8 t/ha to 28.9 t/ha, respectively. The Monika 350 MV hybrid also showed increased yield: from 19.9 t/ha to 25.3 t/ha at the milk-wax maturity stage and from 22.4 t/ha to 27.6 t/ha at the wax maturity stage. Overall, Bilozirskyi 295 SV demonstrated higher productivity than *Monika* 350 MV at all fertilizer levels and at both stages of maturity. The highest dry matter yield (28.9 t/ha) was recorded in Bilozirskyi 295 SV at the wax maturity stage under nitrogen application of N_{135}.

Cultivation of maize hybrids of different maturity groups following alfalfa with seed treatment and foliar feeding using a combination of Emistym C and Ekolyst multinutrient formulation resulted in dry matter yields of 29.0–29.3 t/ha, which was 2.1–5.8% higher compared to nitrogen fertilization at N_{135}. The profitability level ranged from 130% to 136%.

One of the key objectives of modern agriculture is to increase crop productivity and improve yield quality while reducing energy inputs and ensuring the regeneration of soil fertility. Alfalfa (*Medicago sativa* L.) plays an essential role in achieving this goal by contributing to the ecological stability of agroecosystems. Due to its well-developed taproot system penetrating deep into the soil, alfalfa effectively enriches it with

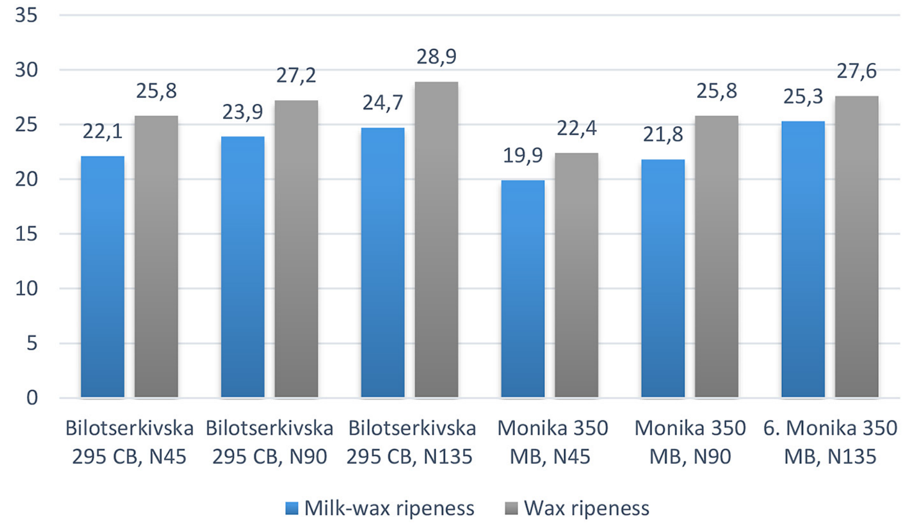

Figure 1. Dynamics of dry matter accumulation by corn hybrids grown after alfalfa (*Medicago sativa* L.), t/ha

organic matter and biologically fixed nitrogen. An increase in humus content in the arable layer is a critical factor in improving soil structure and density, enhancing water retention capacity, and building a reservoir of nutrients – aspects that are particularly important under conditions of global climate change (Kvitko et al., 2010; Kaminskyi et al., 2013).

Analysis of the agrochemical composition of soil after winter wheat harvesting revealed a humus content of 2.54% in the arable layer. Soil acidity also improved, with a pH of 6.2. Cultivation of alfalfa contributed to an increase in available phosphorus content in the arable layer from 90.0 to 105.5 mg/kg of soil and exchangeable potassium from 115.0 to 120.5 mg/kg of soil (Table 3).

The effectiveness of growing alfalfa (*Medicago sativa* L.) as a factor in improving soil fertility has been confirmed on sod-podzolic soils in the Precarpathian region. After three years of using the grass stand, 6.53–6.85 t/ha of dry root biomass accumulated in the arable soil layer, containing 1.57–1.63% nitrogen, 0.21–0.24% phosphorus, and 0.90–0.92% potassium. The total accumulation of nutrients was: nitrogen – 103–112 kg/ha (of which 49–53 kg/ha was symbiotic), phosphorus – 14–18 kg/ha, and potassium – 59–65 kg/ha (Karbivska, 2020).

Under current agricultural development conditions, alfalfa plays an important role not only in the production of high-protein plant products, but also in improving the agroecological condition of the soil due to the formation of a powerful root system. When used as a preceding crop, it contributed to an increase in soil pH by 0.3 units, available phosphorus by 1.6 mg, and exchangeable potassium by 0.6 mg per 100 g of soil. The humus balance in the arable soil layer with a bulk density of 1.26 g/cm³ remained positive and amounted to +1.28 t/ha.

The cultivation of alfalfa (*Medicago sativa* L.) has a positive impact on the agrochemical composition of the soil. By the end of the second year of alfalfa vegetation, changes in soil properties were observed.

The humus content changed only slightly over the two years of alfalfa growth, despite the development of a powerful root system. This is due to the fact that root decomposition begins only in the second year of their life, particularly when soil compaction occurs. The increase in humus content amounted to 0.03% (Table 4).

Two years of alfalfa (*Medicago sativa* L.) cultivation led to a decrease in hydrolyzable nitrogen content in the soil by 3 mg/kg. Leguminous perennial grasses are capable of accumulating mineral nitrogen in the soil through symbiotic nitrogen fixation. However, this nitrogen was utilized for the growth of alfalfa, resulting in a reduced soil nitrogen content, which is compensated by a high yield of green biomass.

Two-year cultivation of alfalfa contributed to an increase in available phosphorus in the soil by 3.7% compared to the level before sowing – up to 405 mg/kg, and an increase in available potassium by 20% – up to 80 mg/kg.

Two years of alfalfa cultivation led to a 28.3% decrease in soil hydrolytic acidity, down to

Table 3. Agrochemical composition of soil after three years of alfalfa (*Medicago sativa* L.) cultivation and winter wheat harvest

Soil parameter	Value
Humus, % (by Tiurin method)	2.54
Content, mg/kg of soil: – Alkali-hydrolyzable nitrogen (Kornfild)	104.0
– Available phosphorus (Chyrikov method)	105.5
– Exchangeable potassium (Chyrikov method)	120.5
Hydrolytic acidity, meq/100 g soil	4.01
pH (salt extract)	6.2
Calcium, meq/100 g soil	1.55

Table 4 Ecological and agrochemical indicators of the soil depending on the duration of alfalfa cultivation (NRF “Ahronomichne”, 2013–2017, M±m)

Cultivation period	Content					Hydrolytic acidity, meq/100 g soil	pH (salt extract)
	Humus content, %	Hydrolyzable nitrogen, mg/kg soil	Available phosphorus, mg/kg soil	Available potassium, mg/kg of soil	Calcium, mg/kg soil		
Before cultivation	2.0±0.01	133±2.83	390±4.24	64±2.83	130±2.83	0.53±0.014	7.0±0.14
2 years	2.03±0.01	130±2.83	405±4.24	80±4.24	130±2.83	0.38±0.028	7.3±0.14
4 years	2.1±0.01	137±1.41	424±5.66	86±4.24	130±2.83	0.40±0.014	7.1±0.14

0.38 meq/100 g. It also resulted in a 4.1% increase in soil solution pH, reaching a value of 7.3.

After four years of growing alfalfa, the majority of agrochemical indicators in the soil stabilized. In particular, four years of cultivation led to a 0.1% increase in humus content in the soil.

A key factor through which leguminous perennial grasses improve soil properties is the accumulation of root biomass and the nutrients it contains. The accumulation of nutrients by leguminous perennials is determined by the development of their underground root systems.

According to Korniychuk O.V. (2013), Hetman N.Ya., Kvitka H.P. (2013), Shramko N.V. (2008), and Churbanova S.A. (2013), the cultivation of leguminous perennial grasses increases the humus content in soil due to the accumulation of root biomass, which is equivalent to the application of 35–40 t/ha of manure. The transformation of root mass into humus begins in the second year of the grasses’ life cycle, when the soil becomes compacted and the mineralization process slows down.

Four years of alfalfa cultivation, due to symbiotic nitrogen fixation, resulted in a 2.9% increase in hydrolyzable nitrogen content in the soil, reaching 137 mg/kg. Since no mineral fertilizers were applied to the alfalfa crop, the plants relied entirely on the nutrients accumulated by the grasses.

Nitrogen cycling studies show that most nitrogen is removed from the soil with the harvested biomass of leguminous perennials. According to Kirilesko O.L. (2013), 75% of nitrogen uptake by these crops comes from atmospheric nitrogen fixation, while the remaining portion is withdrawn from the soil, leading to a reduction in hydrolyzable nitrogen content after cultivation. Mineral nitrogen after legume cultivation is primarily stored in root biomass, and its concentration in the soil is six times lower – especially during dry weather in the vegetation period. Moreover, according to Sobko M.H. (2012), nitrogen accumulated in the soil by legumes is concentrated in their root systems and becomes available only after decomposition. The amount of nitrogen accumulated also depends significantly on moisture conditions. According to Makarenko P.S. (2008), during dry weather, nitrogen accumulation in the soil decreases by 3.5 times.

Four-year alfalfa cultivation increased the content of available phosphorus in the soil by 8.0%. The content of available phosphorus after four years of alfalfa cultivation reached 424 mg/kg. Over four years of alfalfa vegetation, compared to two years, the phosphorus content increased by 19 mg/kg. Four years of alfalfa cultivation led to a 25.6% increase in the content of available potassium in the soil, reaching 86 mg/kg.

The accumulation or reduction of available phosphorus and potassium in the soil depends on changes in green biomass yield and, consequently, the uptake of nitrogen, phosphorus, and potassium by the aboveground plant parts.

During the four years of alfalfa vegetation, soil hydrolytic acidity decreased by 24.5%, amounting to 0.40 meq/100 g. Compared to the two-year cultivation period, the hydrolytic acidity decreased by 5.0%.

The pH of the soil solution increased by 1.4% after four years of alfalfa cultivation. The actual pH was 7.1, corresponding to neutral acidity. Compared to two years of cultivation, the pH of the soil solution increased by 2.7% after four years of alfalfa growth.

CONCLUSIONS

Alfalfa (*Medicago sativa* L.) is a highly efficient agricultural crop that combines agronomic, biological, and environmental value. Due to its well-developed root system and ability to fix atmospheric nitrogen, it significantly enriches the soil with organic matter and nutrients, improves its structure, promotes the accumulation of humus, and enhances water-holding capacity. Using alfalfa as a preceding crop creates favorable conditions for the formation of highly productive agrocenoses, reduces the need for mineral fertilizers and agrochemicals, thereby increasing the efficiency and ecological sustainability of farming. In the context of climate change and the need for resource conservation, including alfalfa in crop rotations is an important direction for the sustainable development of agricultural production.

It was found that the early-ripening winter wheat variety Bilotserkivska semi-dwarf demonstrated a higher grain yield compared to the mid-early variety Tsarivna, regardless of the sowing dates – by 0.27–0.54 t/ha.

Overall, the hybrid Bilozirskyi 295 SV produced a higher yield than Monika 350 MV, regardless of fertilizer levels and growth stage. The highest productivity (28.9 t/ha) was recorded in the Bilozirskyi 295 SV hybrid at the wax ripeness stage under nitrogen application at a rate of N_{135}. At the same time, due to the use of alfalfa as a preceding crop, the dry matter yield increased by 2.1–5.8% compared to the application of nitrogen fertilizers at a rate of N_{135}, with a profitability level of 130–136%.

The agroecological role of alfalfa is defined by its contribution to increasing humus content, hydrolyzable nitrogen, and available forms of phosphorus and potassium in the soil, reducing hydrolytic acidity, and optimizing soil pH reaction.

REFERENCES

1. Annicchiarico, P., Pecetti, L., Abdelguerfi, A., Bouizgaren, A., Carroni, A. M., Hayek, T., et al. (2011). Adaptation of landrace and variety germplasm and selection strategies for lucerne in the Mediterranean basin. *Field Crops Research*, *120*(2), 283–291. https://doi.org/10.1016/j.fcr.2010.11.003
2. Antipova, L. K. (2008). Lucerne – a universal plant for agrocenoses. *Kormy i kormovyrobnytstvo*, *62*, 143–149 (in Ukrainian).
3. Barabash, M., Grebeniuk, N., Tatarchuk, O. (1998). Climate change under global warming. *Vodnyne hospodarstvo Ukrainy*, *9–12* (in Ukrainian).
4. Boiko, P. I., Kovalenko, N. P., Opara, M. M. (2014). Effective diverse crop rotations in modern agriculture. *Visnyk Poltavskoi derzhavnoi ahrarnoi akademii,* (*3*)*,* 20–32 (in Ukrainian).
5. Hetman, N., Karbivska, U., Hryhoriv, Y., Degtyarjov, V., Marenych, M., Malynka, L., Kurhak, V., Golodna, A., Veklenko, Y., Gniezdilova, V. (2025). The influence of fertilization systems on the productivity and quality of different varieties of alfalfa (*Medicago sativa* L.). *Journal of Ecological Engineering*, *26*(4), 220–224. https://doi.org/10.12911/22998993/200031
6. Hetman, N. Ya., Kvitko, H. P. (2013). Agrobiological substantiation of resource-saving technologies for cultivating phytocenoses of perennial and annual fodder crops in field fodder production. *Visnyk ahrarnoi nauky, (9),* 44–47 (in Ukrainian).
7. Hetman, N. Ya., Kvitko, M. H., Tsyganskyi, V. I. (2021). *Liutserna posivna: monohrafiia* [Cultivated Alfalfa: Monograph]. TVORY (in Ukrainian).
8. Kaminskyi, V. M., Saiko, V. F. (2013). Strategy for the development of adaptive agricultural systems and agrotechnologies in Ukraine. *Adaptyvni systemy zemlerobstva i suchasni ahrotekhnolohii*, 5–24 (in Ukrainian).
9. Karbivska, U. M. (2020). Accumulation of root mass and its effect on the nutrient regime of sod-podzolic soil when growing leguminous grasses. *Peredhirne ta hirske zemlerobstvo i tvarynnytstvo*, (67), 84–97 (in Ukrainian).
10. Kvitko, H. P., Mazur, V. A., Davymoka, O. V., Lomachevskyi, S. M., Tkachuk, O. P., Samilyak, M. V. (2010). Adaptive energy-saving technologies for growing perennial legume grasses for fodder in the

conditions of the right-bank Forest-Steppe. *Kormy i kormovyrobnytstvo*, (66), 78–82 (in Ukrainian).

11. Kvitko, H. P., Prokopenko, L. S. (1971). Some issues of evaluating corn grain production for livestock feed in the conditions of the northern Forest-Steppe of Ukraine. *Kormy ta hodivlia silskohospodarskykh tvaryn*, (22), 11–15 (in Ukrainian).
12. Kurhak, V. H., Slyusar, S. M., Krasiuk, L. M., Havrysh, Ya. V. (2023). Dynamics of productivity of meadow agrophytocenoses with the participation of cultivated alfalfa during the formation of the first cut. *Visnyk ahrarnoi nauky*, *10*(847), 19–27 (in Ukrainian).
13. Kutsenko, O. M., Lyashenko, V. V., Kalantai, O. O. (2008). Influence of predecessors on the productivity of winter wheat crops in the conditions of the Left-Bank Forest-Steppe. *Visnyk Poltavskoi derzhavnoi ahrarnoi akademii*, (4), 50–53 (in Ukrainian).
14. Latrach L., Farissi M., Mouradi M., Makoudi B., Bouizgaren A., Ghoulam C. (2014). Growth and nodulation of alfalfa-rhizobia symbiosis under salinity: electrolyte leakage, stomatal conductance, and chlorophyll fluorescence. *Turkish Journal* of *Agriculture and Forestry*. 38, 320–326. https://doi: 10.3906/ tar-1305-52
15. Lykhochvor, V. V. (2004). *Agrobiological bases of winter wheat yield formation in the conditions of the western Forest-Steppe of Ukraine* [Doctoral dissertation, Institute of Agriculture NAAS] (in Ukrainian).
16. Malyarchuk, V. M., Malyarchuk, A. S., Revto, O. Ya. (2024). Influence of technological methods of cultivation on the productivity of cultivated alfalfa. *Tavriiskyi Naukovyi Visnyk*, (138), 96–105 (in Ukrainian).
17. Melnyk, M. V. (2020). Economic efficiency of cultivated alfalfa growing. *Tavriiskyi Naukovyi Visnyk*, (112), 122–129 (in Ukrainian).
18. Methodology for conducting research in fodder production and animal feeding. (1998). *Agrarian Science* (in Ukrainian).
19. Olifirovych, V. O., Lesyk, O. B., Makoviichuk, S. D., Sandulyak, T. M. (2023). Creation and effective use of perennial sown agrophytocenoses on erosion-prone sloping lands. *Visnyk ahrarnoi nauky*, *10*(847), 62–68 (in Ukrainian).
20. Petrychenko, V. F., Hetman, N. Ya., Veklenko, Yu. A. (2020). Justification of cultivated alfalfa productivity during long-term use of herbage under climate change. *Visnyk ahrarnoi nauky*, (3), 20–26 (in Ukrainian).
21. Predko, I. H. (1982). Yield and quality of winter wheat grain depending on predecessors in the Forest-Steppe of Ukraine. *Zemlerobstvo*, (56), 7–12 (in Ukrainian).
22. Protopish, I. H. (2014). Research of ecologically safe and energy-saving technology for growing high-quality soft winter wheat grain in the right-bank Forest-Steppe. *Zbirnyk naukovykh prats Vinnytskoho natsionalnoho ahrarnoho universytetu*, *5*(82), 14–26 (in Ukrainian).
23. Protopish, I. H., Kvitko, H. P., Hetman, N. Ya. (2012). Perennial legume grasses – an indispensable predecessor for winter wheat in the conditions of the right-bank Forest-Steppe. *Kormy i kormovyrobnytstvo*, (72), 34–39 (in Ukrainian).
24. Tucak M., Ravlić M., Horvat D., Čupić T. (2021). Improvement of Forage Nutritive Quality of Alfalfa and Red Clover through Plant Breeding. *Agronomy* J. 11. 2176. https://doi: 10.3390/agronomy11112176
25. Tyshchenko, A. V., Tyshchenko, O. D., Kuts, H. M., Piliarska, O. O., Konovalova, V. M. (2022). Seed productivity of first-year alfalfa depending on herbicide application. *Ahrarni innovatsii*, (11), 92–102 (in Ukrainian). https://doi.org/10.32848/agrar.innov.2022.11.12
26. Tyshchenko, A. V., Tyshchenko, O. D., Piliarska, O. O., Kuts, H. M., Halchenko, N. M. (2021). Seed productivity of first-year alfalfa depending on pest control measures. *Ahrarni innovatsii*, (6), 57–67 (in Ukrainian). https://doi.org/10.32848/agrar.innov.2021.6.12
27. Vozhegova, R. A., Tyshchenko, A. V., Tyshchenko, O. D., Piliarska, O. O., Halchenko, N. M. (2021). Yield and sowing qualities of alfalfa varieties depending on growing conditions. *Visnyk ahrarnoi nauky*, *8*(821), 55–63 (in Ukrainian).
28. Vozhegova, R. A., Tyshchenko, A. V., Tyshchenko, O. D., Piliarska, O. O., Fundyrat, K. S., Konovalova, V. M. (2023). Formation of resistance of seed alfalfa plants under different ecological gradients. *Visnyk ahrarnoi nauky*, *3*(840), 53–62 (in Ukrainian).
29. Zabarny, O. S. (2011). Bioenergetic efficiency of technologies for growing cultivated alfalfa for green fodder. *Kormy i kormovyrobnytstvo*, (70), 60–64 (in Ukrainian).