SECTION 1. AGRONOMY

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1.1 Ecological assessment of the conditions for restoring soil environment through legumes

Today, the vast majority of Ukrainian agricultural producers are focused on growing economically profitable crops, which are mainly grown in monoculture, neglecting crop rotation.

Analysing the processes that take place as a result of growing monocultures, it should be noted that there is a decrease in soil fertility, namely a decrease in humus, nutrients such as nitrogen, phosphorus, potassium, deterioration of the microbiological state of the soil, a decrease in productive moisture, conditions are created that will enable the development of various erosion processes, deterioration of soil structure, a decrease in the number of agronomically valuable aggregates, accumulation of toxins and pollutants, and a decrease in the quality and productivity of agricultural products.

Therefore, it is necessary to restore the agro-ecological indicators of the soil, based on biological processes, namely the cultivation of perennial legumes in the crop rotation, which will naturally accumulate organic matter in the soil in the form of post-harvest and root residues, accumulate symbiotic nitrogen and contribute to the restoration of soil microflora, as well as soil structuring.

A promising plant in this area is the perennial legume galega orientalis, which has positive unifier properties, high productivity, symbiotizes biological nitrogen within 108 kg/ha per mowing, and also contributes to the accumulation of moisture in the soil, organic residues and improves agro-ecological indicators and nutrients.

Growing economically profitable crops in monoculture leads to deterioration of soil condition, namely a decrease in agro-ecologically valuable parameters due to anthropogenic pressure on the soil environment.

1.1.1 Ecological problems of reproduction of soil fertility in agroecosystems

1.1.1.1 Impact of anthropogenic activities on agroecosystems

A modern agroecosystem can be represented as a functional unit that combines natural factors, as well as objects with anthropogenic factors and energy inputs (Fig. 1).

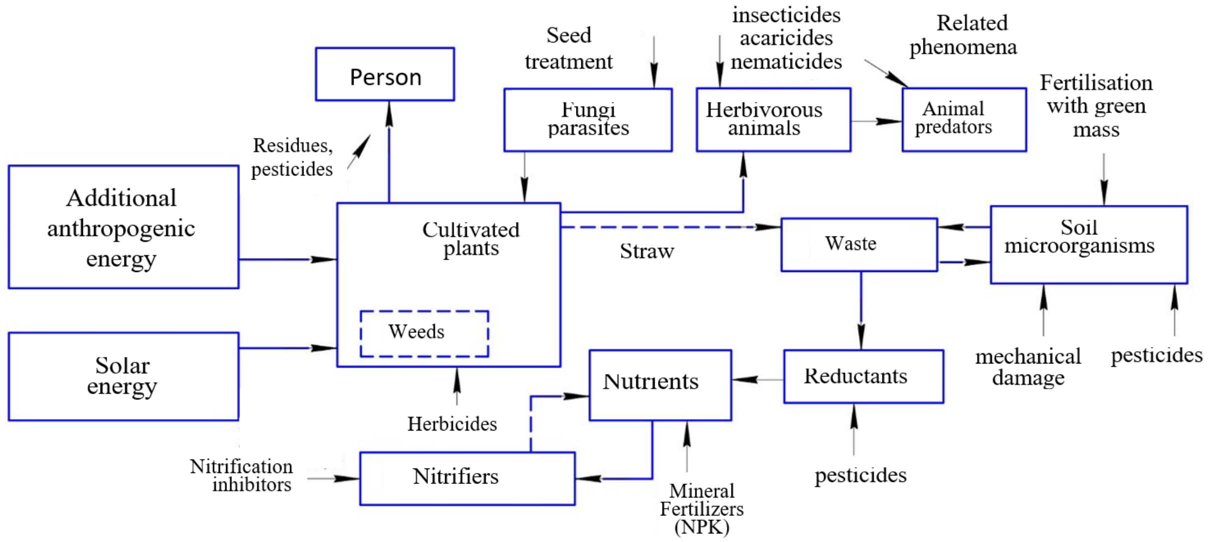


Fig. 1 – Modern agroecosystem

Natural formations are undergoing significant transformation as a result of anthropogenic activity, with the formation of various agricultural formations, namely arable land, hayfields, pastures, orchards and meadows.

Agroecosystems are modified biogeocenoses in the process of human economic activity, which currently occupy a significant place in the biosphere. They are mainly represented by agrobiocenoses, consisting of depleted species of living organisms, which, however, are beneficial to humans in terms of their qualitative and quantitative parameters [2].

For agroecosystems to function, humans create and maintain the conditions for organisms to live. Agroecosystems are characterised by high biological productivity, with the dominance of a particular type of plant or animal organism.

Agroecosystems are inherently unstable and without human support, they are not capable of self-regulation, so they are rapidly destroyed and transformed into natural ecosystems [3, 4].

As a result of active traditional agriculture, the following degradation processes are observed, which negatively affect the condition of agricultural land and contribute to a decrease in its fertility and productivity (Fig. 2).

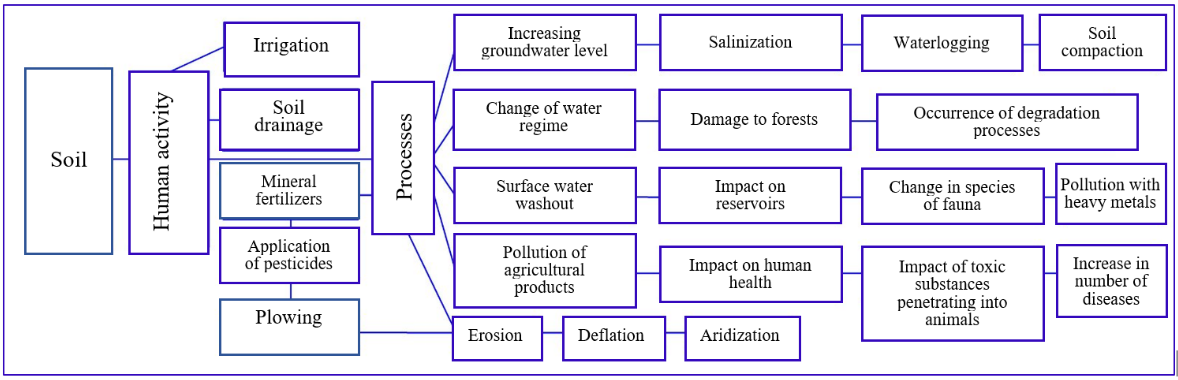


Fig. 2 – Degradation of soil environment due to anthropogenic impact

The impact of human activity on the soil environment results in degradation and destruction processes that lead to a decrease in the productivity of agricultural land [5].

Soil degradation is defined as a decrease in soil fertility and agro-ecological qualities caused by changes in soil formation conditions due to natural or anthropogenic factors. This negative phenomenon is accompanied by a decrease in humus content, destruction of soil structure and a decrease in soil fertility.

Soil degradation also occurs as a result of water and wind erosion, dehumification and decalcification, and over-compaction by agricultural machinery. It is also due to the irrational operation of irrigation systems, which can lead to flooding and waterlogging, secondary salinisation and salinity of soils; due to violations of agricultural practices, overgrowth of weeds and shrubs, unbalanced use of mineral fertilisers, contamination with toxic substances, radionuclides, unregulated grazing, etc. [6].

Therefore, an important factor in restoring soil fertility is the introduction of alternative agriculture, with crop rotation, in which crops that will increase productivity of the soil environment, namely legumes, will be used.

Modern farming systems, of which there are a large number in the world, should have a priority task: to function as close as possible to natural systems, to be environmentally friendly, biological and to provide the world's population with safe agricultural products at all stages of production [7]. The following European countries became the founders of alternative or biological farming in the 60s of the twentieth century: Germany, Austria, Switzerland, the Netherlands and others, in the cultivation of field, vegetable and fruit crops (Fig. 3).

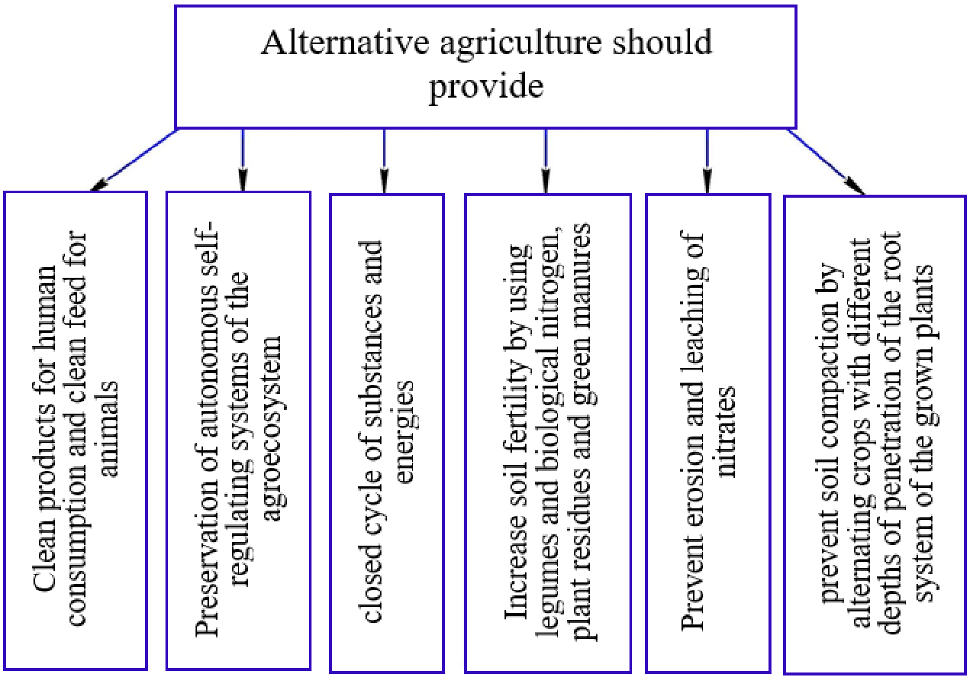


Fig. 3 – The purpose of alternative agriculture

It is important to note that it was during this period that the Green Movement began, which accordingly contributed to the awareness of past mistakes and their correction in the conduct of agricultural and other areas of human activity [8]. Also, in the case of transition to alternative types of farming, it is necessary to direct their activities to the use of the following factors that will most fully meet their focus with the maximum possible use of natural biological factors, which in turn will affect the size and quality of the crop (Fig. 4).

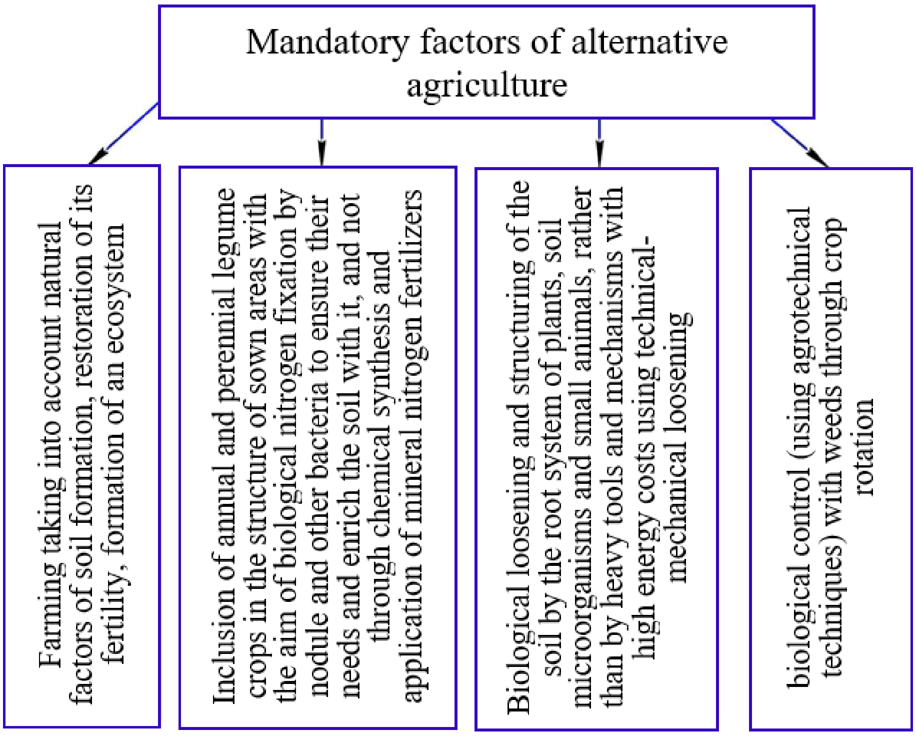


Fig. 4 – Mandatory factors of alternative farming

During agricultural operations, provided that cultivated plants are not restricted of the influence of natural factors such as moisture, light, air, soil nutrients; or provided that antagonistic processes are provided by the action of root secretions of other plants, but not by the use of synthetic herbicides; application of biological methods of protection against diseases and pests on the basis of reasonable crop rotation, through the cultivation of zoned varieties, hybrids and activation of natural enemies which are pests [9].

Through the use of alternative types of farming, the activation and use of the natural cycle of substances that occurs naturally by biological means is achieved, which helps to improve the quality of agricultural products, purify water and air, and contributes to energy conservation and restoration of natural soil fertility. Crop rotation becomes one of the leading links in this type of management, as the crops to be grown in it should complement each other and contribute to increasing yields naturally [10].

It should be noted that the use of alternative types of farming in the early years will not ensure the usual yield of major crops, but over time, when the level of soil fertility gradually recovers, crop yields will increase, and the quality of products that will be environmentally safe and economically affordable is of particular importance [11].

Thus, alternative farming systems primarily ensure high environmental quality of products, promote and maintain soil fertility, and reduce energy costs. To achieve high and desirable results, it is necessary to take into account the soil and climatic conditions of the region, as well as the cultivation of zoned varieties and hybrids, and an important factor is the technical equipment that will meet all the necessary environmental and economic parameters of production.

1.1.1.2 Main factors of soil formation on agricultural land

Multifunctional systems that are of great ecological importance are called soils, the main functions of which include the following parameters, namely: habitat, accumulation, and the main source of substances and energies for organisms, an intermediate chain between biological and geological cycles, a protective barrier and prerequisites for the full functioning of the biosphere, and the creation of optimal conditions for the growth and development of agricultural plants and the maintenance of ecological balance in agricultural landscapes and the natural environment [12].

The following parameters are the main factors and drivers of soil formation (Fig. 5 and Fig. 6).

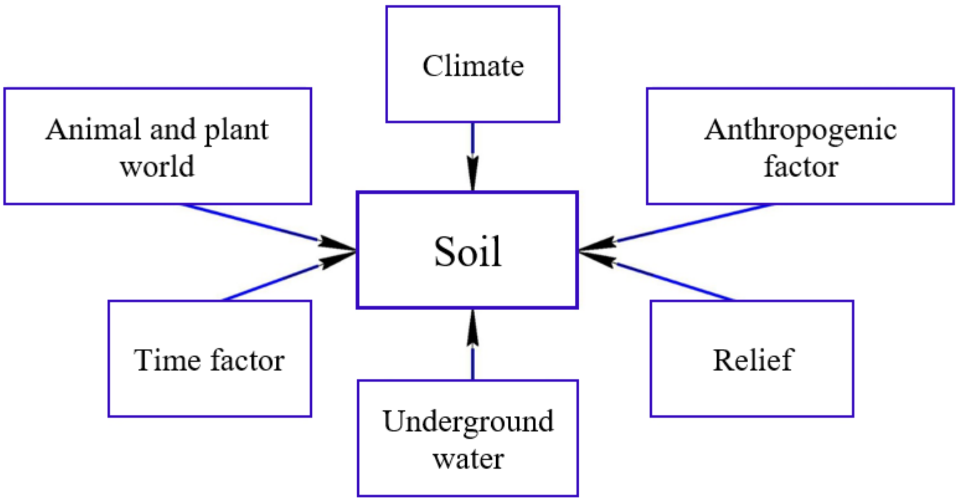


Fig. 5 – Factors of soil formation

The natural course of geological processes is not disturbed, as the influence of natural factors is continuous and mineral and organic substances are in a balanced state.

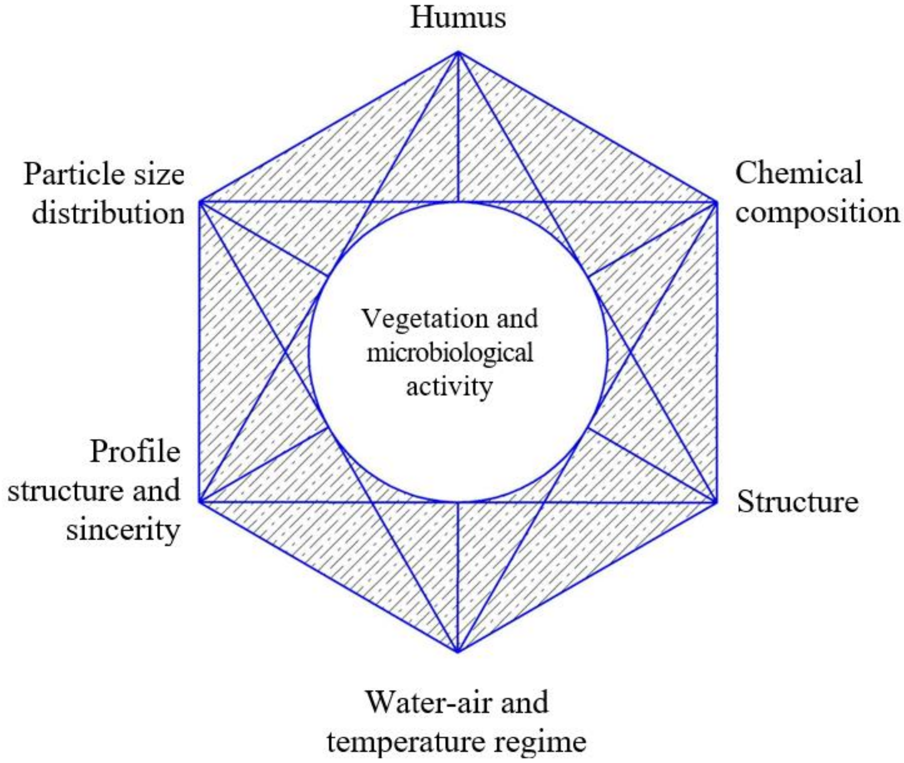


Fig. 6 – Natural fertility factors

As a natural resource, soil is constantly the subject to natural and anthropogenic impacts.

Soil fertility depends on the humus content (Fig. 7). Soil fertility is divided into types: natural, artificial, and mixed.

Natural fertility is determined by the potential reserves of mineral and organic nutrients, while artificial fertility is determined by the application of mineral fertilisers and a range of agronomic measures, including crop rotation, land reclamation, etc.

Crop yields depend on effective soil fertility, which is determined by:

- nutrient, water-air, thermal regimes of soil, content of physiologically active substances, reaction of soil solution, presence of phytotoxic compounds in the soil;
- meteorological conditions of the growing season;
- quality of seed: variety, reproduction;
- phytosanitary conditions: weeds, pests and diseases of cultivated plants;
- anthropogenic activities: soil cultivation, plant cultivation technology, crop rotation, fertiliser system, land reclamation measures, plant protection measures, etc.

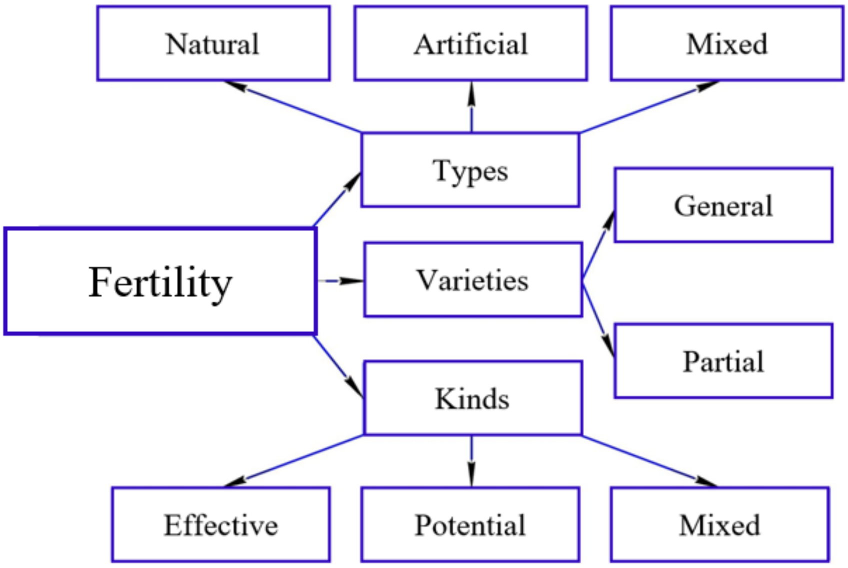


Fig. 7 – Soil fertility

The disadvantages of modern agriculture, which lead to soil environmental degradation, include high level of ploughing, imbalance of biochemicals and energy in agroecosystems, ineffective erosion control systems that lead to a decrease in soil fertility and environmental sustainability, and loss of productive and quality indicators of agricultural land.

Currently, important and urgent issues are the restoration of soil fertility using the most natural methods and measures that will increase soil fertility, improve agronomic and valuable indicators, reduce erosion and allow cultivating environmentally safe agricultural products [13, 14].

1.1.1.3 Greening and improving soil fertility through legumes

In alternative farming systems that have emerged as a result of greening of the agricultural sector, the priority areas of development are the application of organic fertilisers using maximum possible resources, namely manure, compost, post-harvest residues, green manure, as well as soil protection systems and environmentally sound plant protection systems against pests. The use of ecological farming systems results in a symbiosis of natural and anthropogenic factors, which makes the agricultural sector acceptable to both humans and nature. The main tasks of ecological farming can be classified as the production of environmentally safe, economically viable agricultural products, as well as the preservation and improvement of soil fertility [15, 16].

Due to the intensification of farming in recent decades, the agricultural sector has been burdened with environmental problems, as the main means of production – soil – although of natural origin, is degraded due to anthropogenic pressure, which is shown in the loss of soil structure, over-compaction, deterioration of water permeability, and accumulation of toxins [17].

Scientists consider the ecologically acceptable share of arable land to be 40%, meadows and pastures – 30%, forests – 30% of the country's territory, but as for Ukraine, these parameters do not meet environmental standards, namely arable land occupies 57%, meadows and pastures – 26% and forests – 17%. So, environmental optimisation is needed, which will reduce the share of arable land and increase the number of meadows and forests. Another important factor is the development of a land structure analysis on a farm-by-farm basis, and the introduction and observance of crop rotation with mandatory legumes.

Basic laws of agriculture that will contribute to the improvement and restoration of soil environment include the following:

- indispensability and equivalence of life factors;
- minimum, optimum and maximum;
- combined action and interaction of life factors;
- return of nutrients to the soil;
- fruit change;
- critical periods.

G. Kant, who is considered to be its founder, wrote about biological or alternative agriculture in his works [18, 19].

The main three principles of biological farming are as follows (Fig. 8):

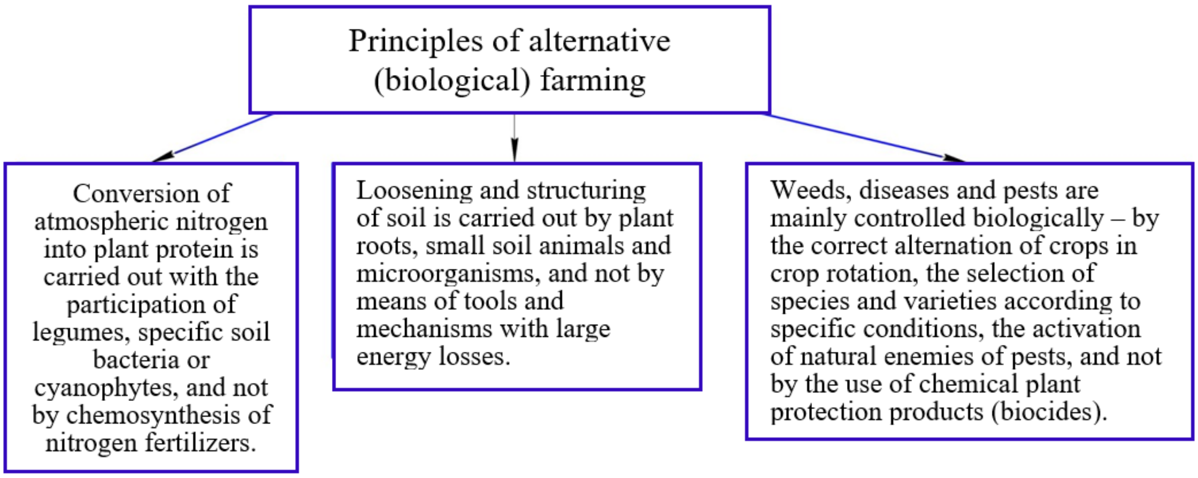


Fig. 8 – Principles of biological farming

1) Air nitrogen is converted into plant protein by legumes, specific soil bacteria or cyanophytes, rather than by chemosynthesis of nitrogen fertilisers;

2) Soil loosening and structuring is carried out by plant roots, small soil animals and microorganisms, not by means of tools and mechanisms with high energy losses;

3) Weeds, diseases and pests are controlled mainly by biological means – by proper crop rotation, selection of species and varieties according to specific conditions, activation of natural enemies of pests, and not by the use of chemical plant protection products (biocides).

The implementation of the first and second principles is possible through the use of legumes in crop rotation, which, due to their biological and ecological characteristics, are able to accumulate biological nitrogen, through symbiosis with nodule bacteria, have a large amount of post-harvest residues and root residues, which create favourable conditions for the accumulation of humus and development of positive soil microflora, structuring and loosening of the soil is carried out by the fibrous root system of crops [20].

Legumes include the following crops: soybeans, peas, beans, chickpeas, peanuts, lentils, alfalfa, sainfoin, sweet clover, eastern galea, clover, lupine, vetch, etc. (Fig. 9) [21, 22].

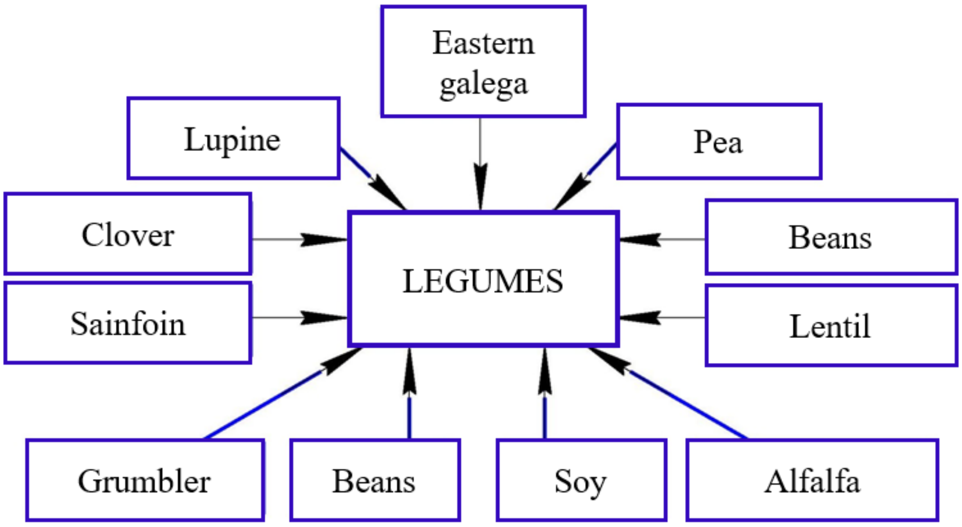


Fig. 9 – Legumes

The territory of Kirovohrad region is favourable for growing legumes, and their environmental impact on agroecosystems is therefore undeniable.

Soybeans are an annual herbaceous cultivated plant of the legume family.

Scientists have shown in their research that by combining two of the most important physiological processes – photosynthesis and biological nitrogen fixation – the crop is able to meet its nitrogen requirements and improve nitrogen balance and soil fertility. The crop is able to fix atmospheric nitrogen when there is a sufficient amount of Bradyrzobium bacteria in the soil or when seeds are inoculated. It has been established that soybeans receive 25 to 75% of the nitrogen they need through nitrogen fixation.

According to the research of A.O. Babych, on average, from 21 to 80 tubercles are formed on one plant. They are located mainly in the topsoil on the main and lateral roots [23]. First tubercles on soybean roots appear a week after germination, and in 10-14 days they can satisfy most of the nitrogen demand of plants. Nitrogen is most intensively fixed from the atmosphere by tubercle bacteria and enters the plant from the flowering phase to bean filling at the air temperature of 24-28°C and relative humidity of 40-80%, after which it gradually decreases as the plant approaches maturity [4].

Chickpea is an ancient crop in the world's crop production [25].

Chickpea has high agrotechnical characteristics. Chickpea is a good precursor for many crops. Due to the biological characteristics of the root system of legumes, which include chickpea, symbiotic nodule bacteria can develop on the roots under favourable hydrothermal conditions. The vital activity of nodule bacteria helps to bind atmospheric nitrogen and convert it into a form available to plants. Due to its symbiotic properties, under favourable conditions, chickpea, together with root residues, accumulates 50-60 kg/ha of symbiotic nitrogen. The roots of this plant are able to absorb phosphorus and calcium from deep soil layers and move them to higher soil horizons, where they are absorbed by subsequent crops in the crop rotation [26].

Lentils are an annual plant of the legume family, quite cold-resistant, with a minimum seed germination temperature of +4...+50°C [27].

One of the main biological features of lentils, as well as other legumes and perennial legumes grown in agriculture, is the ability to absorb air nitrogen with the help of nodule bacteria. The symbiosis between bacteria and legumes not only increases the yield, but also increases protein and vitamin content of the crop. Under favourable conditions, proteins are formed in the grain and green mass of legumes, mainly from air nitrogen.

It has been established that lentils can accumulate atmospheric nitrogen in the soil, improving its fertility and structural properties. Depending on the conditions of development, its amount during the growing season ranges from 35-140 kg/ha, which is equal to 10-20 t/ha of manure [28].

Lentils also have the following economic values: they free up space early and use moisture sparingly, leaving significant reserves in the soil, so the crop is valuable as a precursor and as a source of ecological fertiliser. It is also important to add that grain yields after lentils increase by an average of 0.3-0.6 t/ha [29].

For example, seed alfalfa, one of the traditional legumes grown in our region, is a strong nitrogen fixer [30]. Depending on the growing conditions, 1 hectare of this crop can fix 200-250 kg of nitrogen (and even more), and the root system leaves the same amount of nitrogen, phosphorus, potassium and other elements as the application of 45-60 t/ha of manure [31].

The roots of the crop penetrate into the soil 2-3 m or more and bring calcium, phosphorus and other elements to the top layer, enriching it with nutrients.

The great value of the crop is that it generates high yields and quality through significant nitrogen fixation, does not require the use of expensive and environmentally harmful nitrogen fertilisers, and therefore plays a major role in the biologisation of fodder production and is a valuable component of energy-saving technologies.

Due to their ability to improve the agrophysical, agrochemical and biological properties of soils, all legumes are the best predecessor for all crops in a crop rotation.

Galega orientalis L. is a promising valuable perennial agricultural crop that is gaining widespread use due to its biological and ecological characteristics, which are especially valuable in the context of rapid climate change.

Like the vast majority of legumes, under favourable conditions, galega oriental undergoes symbiotic relationships with nodule bacteria, which are formed on the roots of plants from the stage of stemming. The shape of the nodules is oval, 2-4x1-1.5 mm in size [32]. During the process of entogenesis to the phase of butonisation, the nodule weight increase is observed, which sometimes reaches 400 kg/ha. After the disposal of the simulation equipment (mowing), the vast majority of nodules die off due to the cessation of the supply of plastics. Since galega oriental is a multi-rooted crop, nodules are continuously formed on young roots as the root system grows and regenerates.

Traditional legumes grown in Kirovohrad region also include sainfoin, which is a valuable fodder and ameliorative crop that can successfully compete with alfalfa when grown in the Steppe zone of Ukraine without irrigation [33].

When grown for green manure, sainfoin loosens the soil well and improves its structure, protects against erosion processes (especially on slopes), and suppresses weed growth. At the same time, it has individual positive characteristics, namely: a nitrogen fixer that is undemanding to soil fertility, and thanks to its powerful root system, it is able to penetrate to a depth of 40-100 cm and absorb hardly soluble calcium and phosphorus compounds from the lower soil layers; a powerful unifier, with low rates of pest and disease damage compared to other legumes.

Taking into account the data from scientific sources, it should be noted that the use of legumes in agricultural practice will allow for the active implementation of alternative farming and will contribute to the increase of soil fertility, humus growth, accumulation of biological nitrogen, improvement of the structure of the soil environment, increase of the level of positive soil microflora, which in turn will allow for the production of environmentally safe crop products.

1.1.2. Place and conditions of the research

The and fund of Kirovohrad region consists of 2458.8 thousand hectares, of which 2035.7 thousand hectares are agricultural land. The soil cover of the region is characterised by a high level of fertility.

The research area of Kirovohrad region belongs to the temperate continental and moderately warm climate.

The thermal period ranges from 240-250 days with an average daily temperature above 0°C.

The climate in the steppe part is moderately warm and moderately continental with insufficient moisture, hot summers and mild winters, sometimes cold.

As for moisture, precipitation is unevenly distributed throughout the year. Thus, the minimum amount falls in the winter months. A moderate increase occurs from April to July, and its maximum amount falls in June and July in the form of heavy rains, and in August, a decrease in precipitation is again observed and continues until the end of the year. As a result, in the conditions of Kirovohrad region, namely in the southern and southeastern parts, there is a periodic lack of soil moisture.

The thermal regime has significant fluctuations throughout the year. For example, spring sees an intense rise in temperatures.

Summers are mostly warm and cloudy, with the average monthly temperature in July in the south reaching -22° and the maximum +38°. In summer, precipitation is mainly rainfall, 7-10 days a month, although there are long periods of rain-free weather.

In autumn, cloudy days with night frosts and a gradual drop in temperature prevail. Thus, in mid-November, the average daily air temperature goes below 0°.

In winter, there is generally little snowfall, mild weather with frequent thaws, with a sharp rise in air temperature to 4-9°C, sometimes up to +13°C. Very cold winters are rare, with the average temperature of the coldest period (January-February) ranging from -28.3° to 35.4°C.

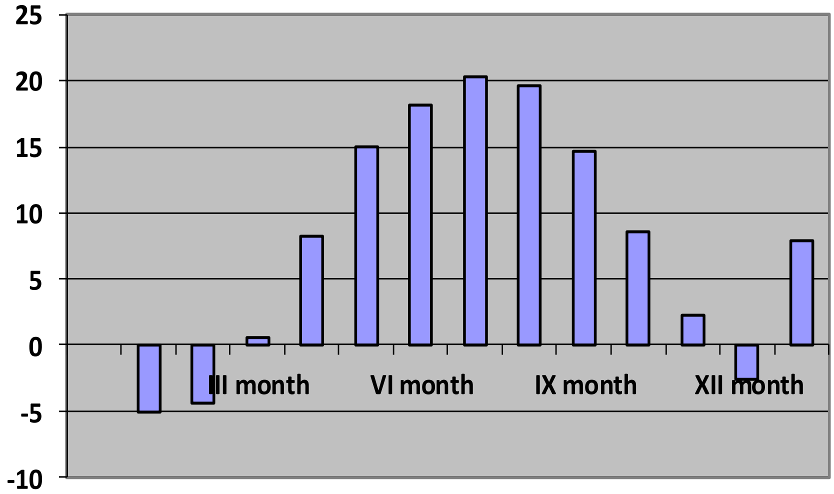


Fig. 10 – Average monthly and annual air temperature in the study area, ^{0}C, (according to the Kirovohrad Hydrometeorological Office)

The temperature regime is favourable for the growth and development of most zoned crops (Fig. 10).

In Kirovohrad region, the main factor affecting crop yields is the amount of precipitation (Fig. 11).

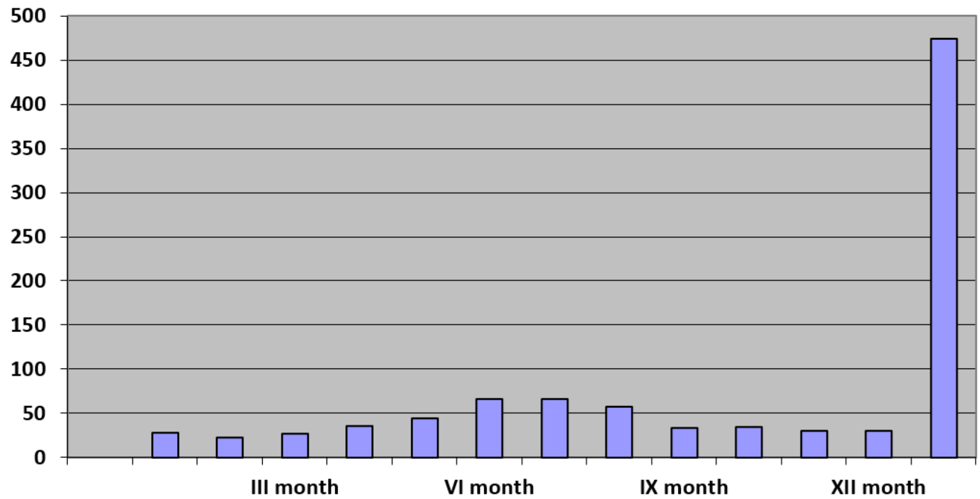


Fig. 11 – Average monthly and annual precipitation in the study area, mm (according to the Kirovohrad Hydrometeorological Office)

In general, weather conditions are favourable for growing all zoned crops, as well as for the development of horticulture and gardening.

1.1.3. Research results and analysis

The studied soils are mainly chernozems, which are characterised by high natural fertility, but about 200 hectares are eroded soils with a shortened humus horizon, reduced nutrients and reduced agro-ecologically valuable indicators that need to be restored to reduce active soil degradation and destruction on the farm.

It has been established that the nutrient content of the soil is decreasing every year, as monocultures such as sunflower prevail on the farm, which leads to an impoverishment of soil environment and, as a result, a decrease in the yield of crops grown.

For productive farming to have a favourable impact on the soil environment, namely the restoration of its fertility, nitrogen returns should be in the range of 90-110%. As for phosphorus, its return should be more than 100% before leaching. In the case of potassium, this element is the most abundant in the soil, so in the coming years, the farm's black soil will be within acceptable parameters for potassium recovery.

As noted earlier, sunflower has been growing on a large part of the farmland for the past five years, and it is an economically profitable crop for the farm. Sunflower is a demanding crop in terms of soil nutrition and, together with crops, it removes 5-6 kg of nitrogen, 2-2.5 kg of phosphorus and 10-12 kg of potassium from the soil per 1 m^2.

During the years of research (2023-2024), there was a decrease in soil fertility indicators.

According to the agro-ecological certification, in 2022, according to the comprehensive studies conducted, the ecological and agrochemical assessment of soils was on average 80 points.

It has been established that over the past three years, the studied indicator has been steadily decreasing due to monoculture cultivation (Fig. 12).

As can be seen from Fig. 12, the indicators of the ecological and agrochemical assessment of soils have been deteriorating over the years of research. Thus, in 2021, the indicator was 80 points, which was 20 points lower than the benchmark. In 2022, the indicator decreased by 5 points and 25 points, in 2023 by 16 and 36 points, and in 2024 by 20 and 40 points.

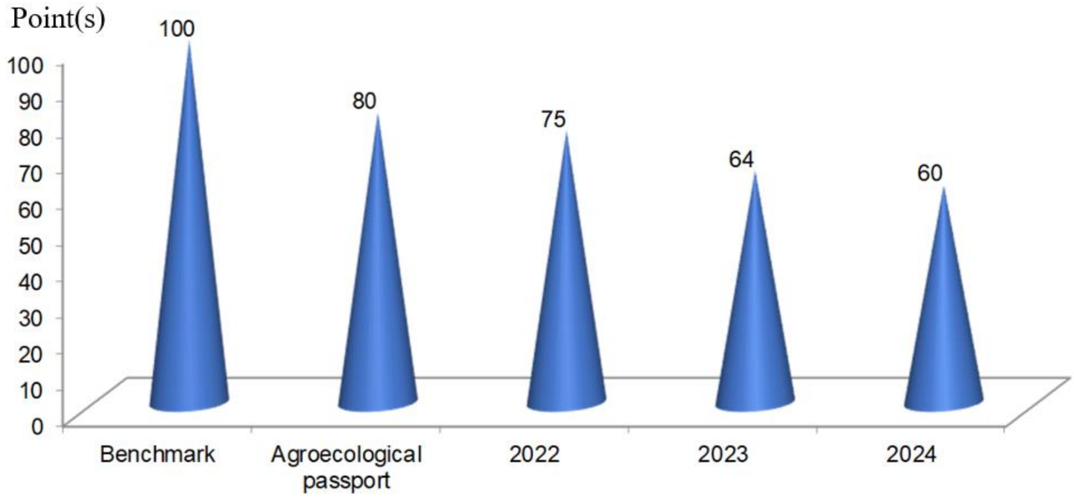


Fig. 12 – Ecological and agrochemical assessment of the studied soils, points

Also, in our research, we noticed how the nutrient indicators decreased over the years of research, due to the cultivation of monoculture (Fig. 13, Fig. 14, Fig. 15).

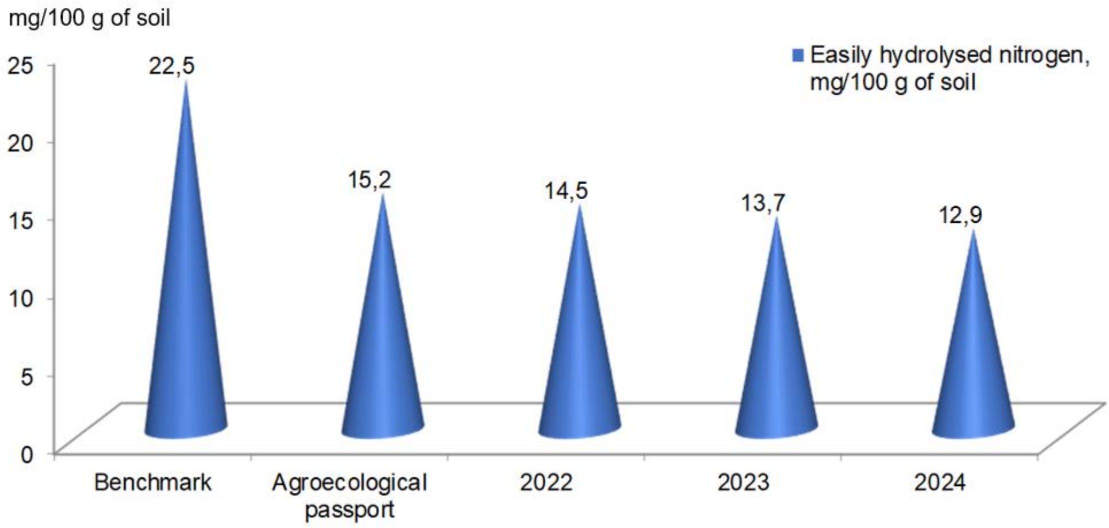


Fig. 13 – Indicators of easily hydrolysed nitrogen during 2022-2024 research, mg/100 g of soil

According to Fig. 13, the studied indicators of easily hydrolysed nitrogen were as follows: in 2021 – 15.2 mg/100 g of soil, which was 7.3 mg/100 g of soil lower than the standard, while in 2022 the indicator decreased to 14.5 mg/100 g of soil, which was 8 mg/100 g of soil below the benchmark and 0.7 mg/100 g of soil below the benchmark in 2021.

A similar downward trend in nitrogen content was observed over the next two years of research. Thus, in 2023, the indicator decreased to 13.7 mg/100 g of soil, and in 2024 to 12.9 mg/100 g of soil, which was 8.8 and 9.6 mg/100 g of soil lower than the benchmark, respectively.

In our research, we also paid attention to mobile phosphorus (Fig. 14).

Our research has shown that the amount of mobile phosphorus, according to the agro-ecological passport, was 14.9 mg/100 g of soil, which was lower than the standard by 2.7 mg/100 g of soil. A downward trend in the studied indicators was observed over the years of research, both in relation to the benchmark and to the environmental certification data.

Thus, in 2022, the mobile phosphorus indicator was 13.8 mg/100 g of soil, which was lower than the standard and the agroecological passport indicators by 3.8 mg/100 g of soil and 1.1 mg/100 g of soil, respectively. The lowest levels were recorded in 2023 and 2024, which were 13.4 and 13.1 mg/100 g of soil, respectively.

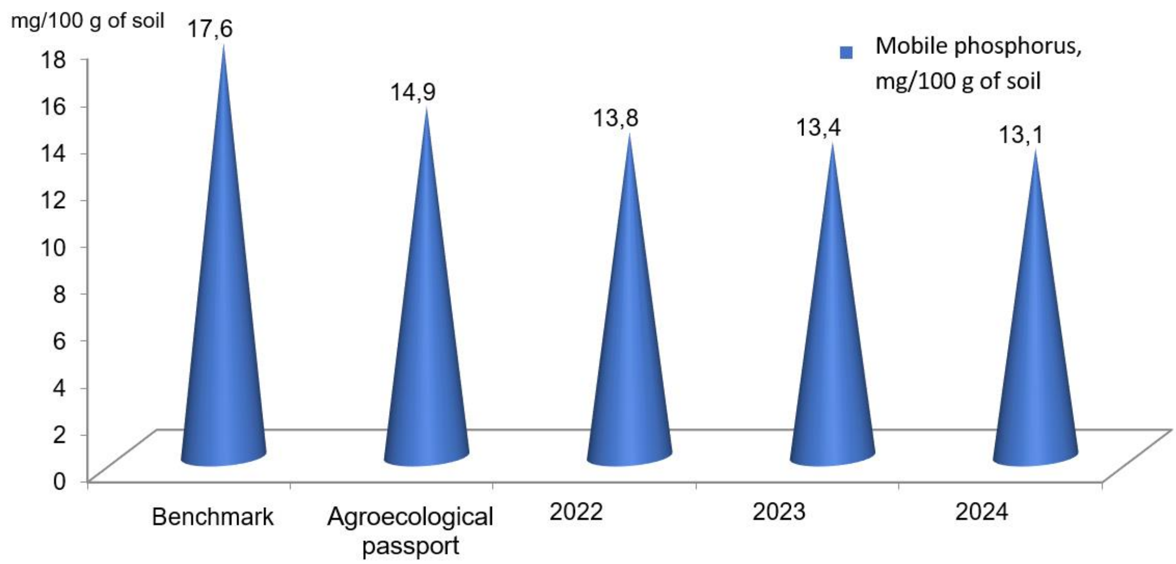


Fig. 14 – Indicators of mobile phosphorus during the 2022-2024 research period, mg/100 g of soil.

In our studies, we found that the exchangeable potassium values varied over the years of research and were lower than the benchmark and agroecological certification data (Fig. 15).

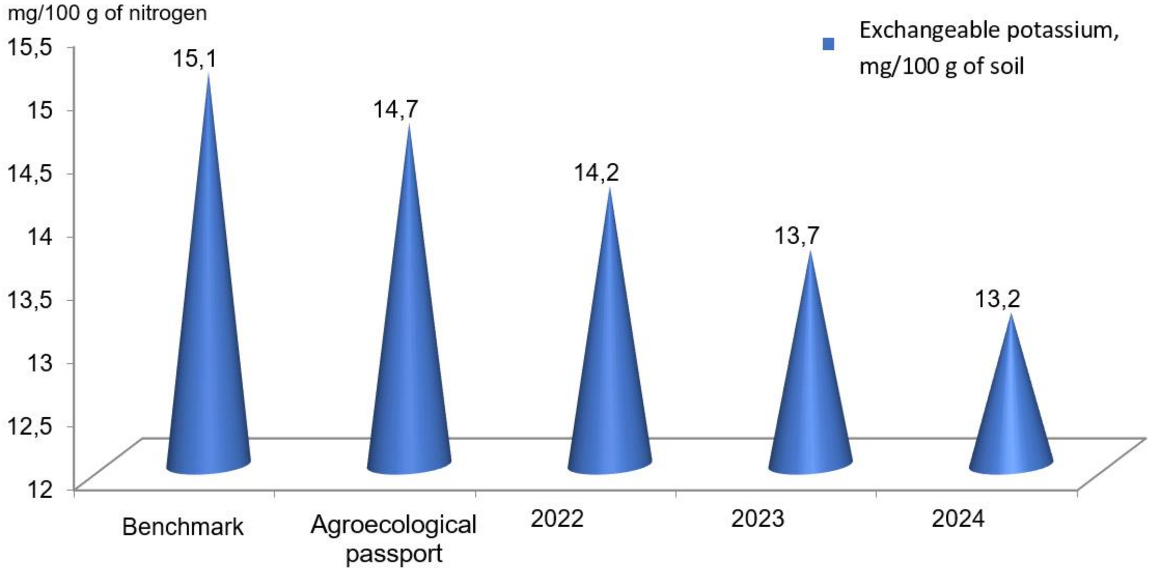


Fig. 15 - Indicators of exchangeable potassium during 2022-2024 research, mg/100 g of soil.

Analysing the indicators of exchangeable potassium content (Fig. 15), we can note that the studied indicator was the highest in 2021 – 14.7 mg/100 g of soil, but lower than the standard and agroecological passport by 0.9 mg/100 g of soil and 0.5 mg/100 g of soil. Whereas, in 2023 and 2024, the values of exchangeable potassium were the lowest and amounted to 13.7 and 13.2 mg/100 g of soil, respectively.

It was found that during the years of research there was a decrease in the indicators of humus in the soil (Fig. 16).

As can be seen from the graph, the indicators in the experimental plots in 2022 were 5.4%; in 2023, the humus indicators were 4.9%, and in 2024, this indicator was 4.7%. Compared to 2021 and the benchmark, the indicators for the years of research were lower by 0.8%, 1.3%, 1.5%, and 0.4%, 0.9%, 1.1%.

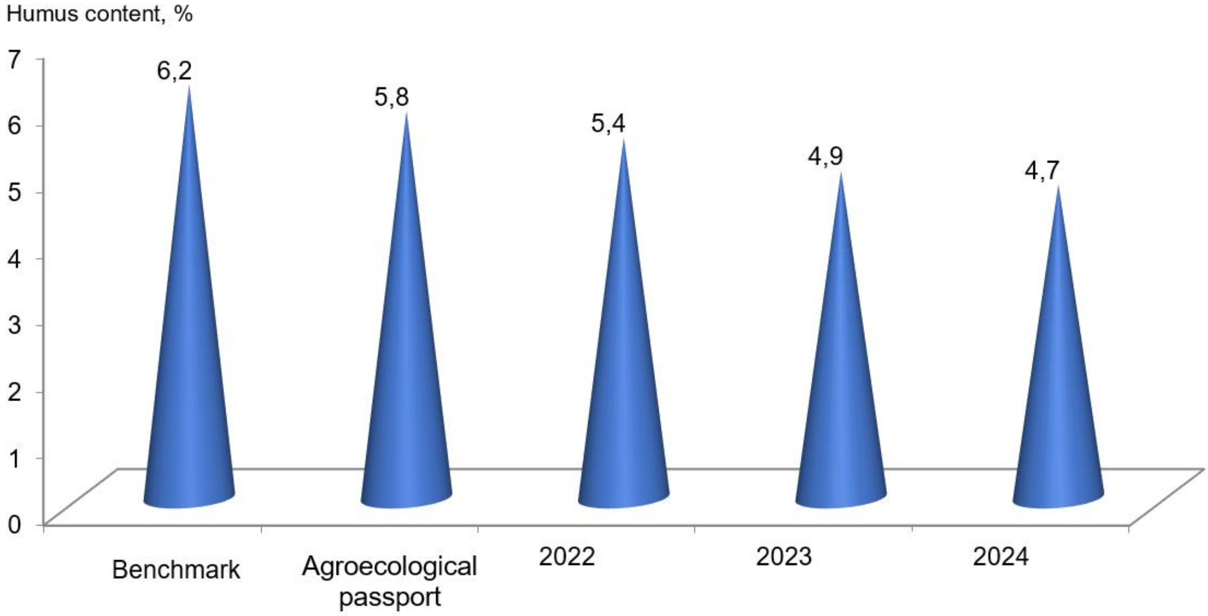


Fig. 16 – Humus indicators during 2022-2024 research period, %.

Our research for 2022-2024 showed a decrease in humus content over the years and in the main nutrients in the soil due to sunflower cultivation in monoculture.

1.1.3.2. Ecological substantiation for growing pulses

In our research, we found out how legumes, namely perennial legumes such as alfalfa and eastern galea, contributed to the improvement of agro-ecological indicators of the soil.

Alfalfa is a legume. In modern agriculture, alfalfa is used for animal feed. It is fed fresh to animals; preparation of silage (haylage); preparation of alfalfa hay and pellets; medicinal purposes; improvement of soil fertility, accumulation of nitrogen in soils.

Alfalfa usually has the highest nutritional value of all common crops for hay production. Alfalfa provides protein- and vitamin-rich fodder for livestock in the form of green mass, hay and hay meal. The leaves contain up to 19-20% protein, a large amount of vitamins - A, C, PP, etc., 0.24% phosphorus and 1.49% calcium.

The fodder value of alfalfa is combined with its high productivity. It grows quickly (3-4 times during the growing season) and provides valuable, highly nutritious fodder in summer. On average, the yield of alfalfa green mass is between 400-600 cwt/ha, and hay 50-120 cwt/ha.

Less commonly, alfalfa is used as a pasture crop. Fresh alfalfa can cause tympanitis (a digestive disorder) in livestock, so because of this danger, livestock should be carefully grazed on alfalfa.

Alfalfa sprouts are also used in salads and sandwiches, and dehydrated alfalfa leaf is commercially available as a dietary supplement in several forms, such as tablets, powders and tea.

Ecological features of alfalfa. Alfalfa seeds germinate at temperatures of 5-6°C, and seedlings can withstand frosts of -5 to -6°C. In spring, alfalfa begins to develop at temperatures of 8-10°C. Alfalfa is a fairly winter-hardy crop, withstanding temperatures down to minus 25°C in snowless winters. Under snow cover, its crops do not freeze at temperatures of minus 40°C and below.

Seed alfalfa is a long-day plant. It is a light-loving plant that does not tolerate shade, especially at the beginning of growth. Alfalfa is quite demanding on soil fertility. The highest yields are obtained on fertile, deep and calcium-rich soils. Alfalfa does not tolerate close groundwater. Soils with pH of 7 are the most suitable for its cultivation. Under irrigated farming conditions, it prevents soil salinisation. Alfalfa grows well on sandy clay soils with sufficient humus content and a low content of calcium or marl compounds in deeper horizons.

Agronomic importance of alfalfa. Like other legumes, alfalfa's root system is in symbiosis with the bacteria Sinorhizobium meliloti, which can fix atmospheric nitrogen, which contributes to the production of high-protein feed regardless of the availability of nitrogen in the soil. The nitrogen-fixing capacity of alfalfa (which increases the nitrogen content in the soil) and the use of alfalfa as animal feed significantly reduces the cost of nitrogen fertilisers and increases agricultural efficiency, improving the ecological situation of soils.

Eastern galega is a perennial plant of the legume family, endemic to the Caucasus. Galega is used for fodder, energy, and agroecological purposes. Various types of feed are prepared from the above-ground mass and the green mass is used directly on pasture, in mown form as hay, haylage, and silage. Hay made from eastern galega contains a lot of nutrients, namely protein, phosphorus, calcium, essential amino acids, and is characterised by high feed values. As for the green mass, it contains about 23.6% protein, 2.5% fat, 20.4% fibre, 44.5% nitrogen-free extractives and vitamin P - 276 ml%. One centner of green mass contains an average of 24 feed units, the digestible protein content reaches 135 g, which is twice as high as that of alfalfa.

The crop is characterised by early maturity and high productivity, and provides green mass in the early spring.

Environmental features of galega. Galega is a highly plastic crop that is adaptable to different soil and climatic conditions and is also characterised by frost, winter and drought resistance.

Thus, galega crops can withstand frosts without snow cover down to -25°C, and under snow cover down to -40°C. It is important to note that the crop can withstand sudden temperature drops in spring and autumn down to -3-5°C.

Seeds germinate at soil temperatures starting at +5...+6°C, and seedlings can withstand frosts down to -3...-4°C. When the temperature increases to +18...+20°C, the number of seedlings increases.

In the following years of life, the germination of crop seedlings occurs at a temperature of +3...+5°C.

As for soils, sandy loam and light loamy soils are the best for eastern galega, and the crop also grows well on fertile, structural and moist soils. The optimal reaction of the soil solution for the crop is close to neutral. Galega germinates well in regions with at least 450-500 mm of moisture per year.

Agricultural importance of galega. The culture is a good precursor, as under favourable conditions it exhibits symbiotic properties with nodule bacteria, which are formed on plant roots from the stemming phase. During ontogenesis to the budding phase, an increase in nodule mass is observed, sometimes reaching 400 kg/ha. After mowing, the majority of the accumulated nitrogen is transferred to the soil environment and can be used by subsequent crops in the crop rotation. In addition, a large amount of post-harvest residues and root mass remains after galega, which has a positive effect on the restoration of the humus layer.

Our field experiments were carried out on ordinary medium-humus black soils of transition to deep.

This work is aimed at introducing the cultivation of alfalfa of Synyukha variety and eastern galega of Salyut variety to determine the maximum unifying properties of crops by comparing the accumulation of aboveground and underground crop mass. The research was carried out according to general methods for growing legumes and in accordance with generally accepted methods [34].

The area of the experimental plot was 32 m^2 in triplicate. The sowing method is wide-row with a row spacing of 45 cm, the predecessor is sunflower. The seeding rate is 4 million/ha. Sowing depth is 3-4 cm. The sowing date was 20 October. The general agricultural background of the experiment was $N_{60}P_{60}K_{60}$.

Phenological studies of alfalfa and galega cultivation have shown that the second crop has advantages in growth and development.

In our studies, we paid attention to the following phenological parameters: dynamics of plant density, plant height, number of nodules on the plant root system (total and active) and crop yield.

It was found that the onset of the growth and development phases depended on the crop grown (Fig. 17).

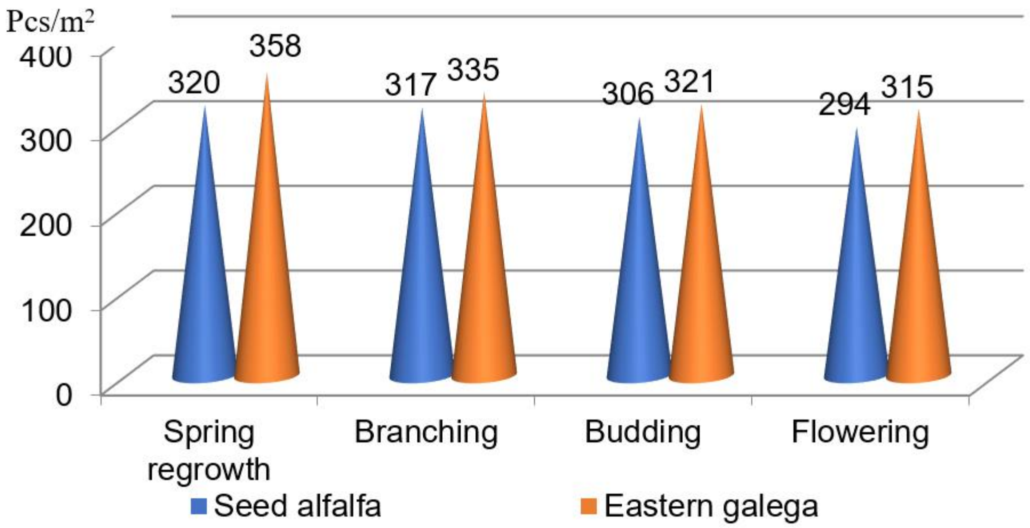


Fig. 17 – Density dynamics of alfalfa and eastern galega plants by growth and development phases, pcs./m^2 (average for 2022-2024)

Our research has shown that the density of eastern galega plants was higher than that of alfalfa.

Thus, alfalfa's indicators of ‘spring regrowth’, on average, over the years of research, were within 320 units/m^2, while in the case of eastern galega this indicator was 38 units/m^2 higher.

In the ‘branching’ phase, thinning was observed in the crops of the studied crops: the density of alfalfa was 317 pcs/m^2, and in the eastern galega 335 pcs/m^2.

A similar trend was observed in the subsequent phases – ‘budding’ and ‘flowering’, which respectively amounted to 306 and 294 plants/m^2 (alfalfa) and 321 and 315 plants/m^2 (eastern galega).

Analysing the data obtained, it can be noted that eastern galega had a higher plant density in the crops compared to sowing alfalfa, which was 6.7-10.6% higher.

Also, in our research, we paid attention to the height of the plants of the studied crops (Fig. 18).

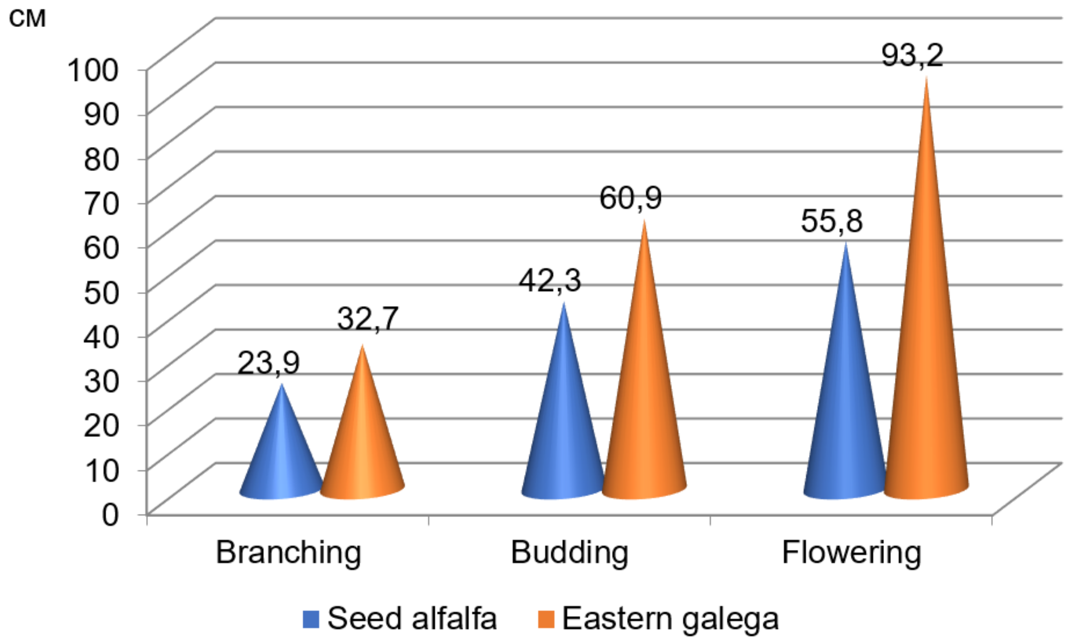


Fig. 18 – Plant height of alfalfa and eastern galega by growth and development phases, cm (average for 2022-2024)

Our studies have shown that the height of alfalfa plants in the ‘branching’ phase was 23.9 cm, while the height of galega was 32.7 cm, which was 8.7 cm higher than that of alfalfa.

With the onset of the ‘budding’ phase, there was an increase in the height of the studied plants, such as alfalfa and eastern galega. Thus, the height of alfalfa was 42.3 cm, which exceeded the branching phase by 18.4 cm. Whereas the height of the eastern galega in the ‘budding’ phase was 60.9 cm, which was 28.2 cm higher than in the previous phase of development. The height of galega plants was 18.6 cm higher than that of alfalfa plants in the budding phase.

With the onset of the ‘flowering’ phase, the maximum height was observed in the crops of the studied plants compared to other phases of crop growth and development.

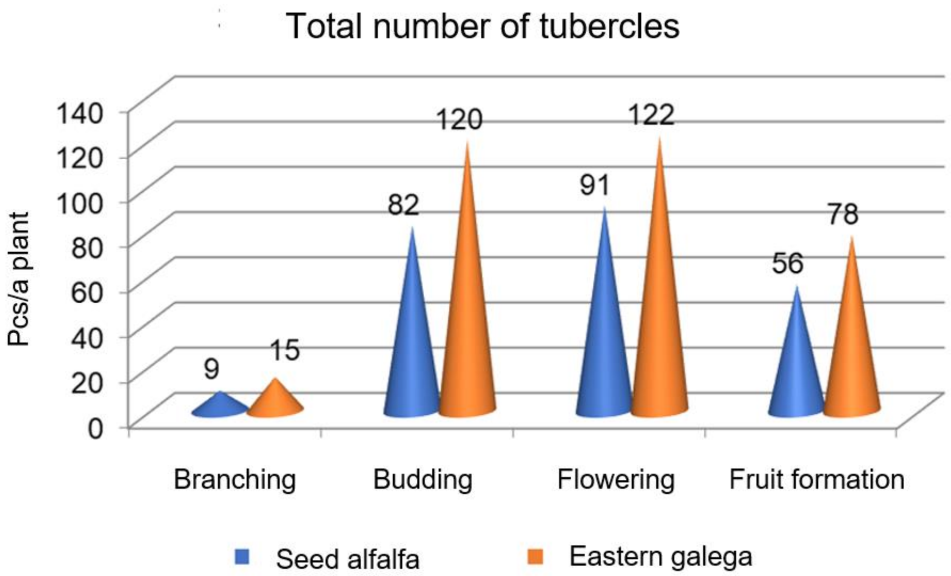
Thus, in galega crops, the studied indicator was within 93.2 cm, while in alfalfa the sown index was 55.8 cm, which was lower than the galega index of 37.4 cm.

According to Fig. 18, we can state that the height of galega plants was higher compared to sowing alfalfa, in the range of 26.9-40.2%.

An important feature of the studied legumes is their ability to bind atmospheric nitrogen due to nodule bacteria that are in symbiosis with legumes and germinate on their roots.

All legumes are good predecessors in crop rotation.

As our research has shown, nodules actively grew in the areas where eastern galega was grown (Fig. 19)



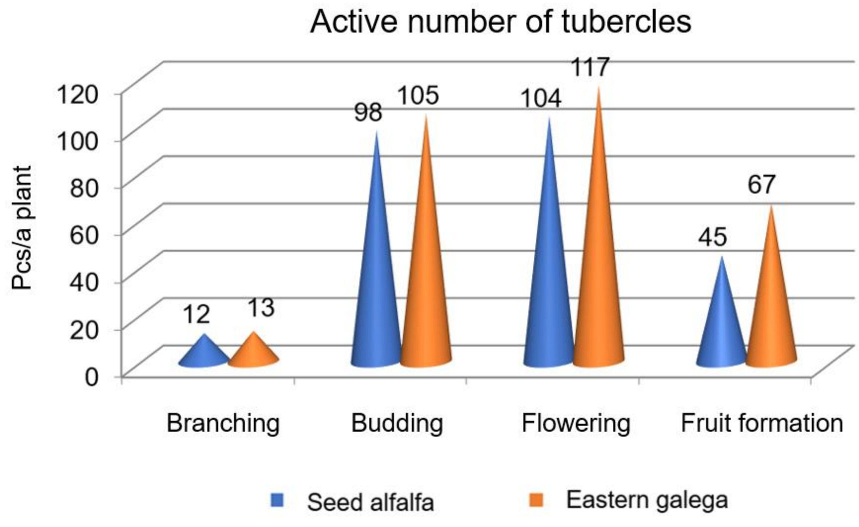


Fig. 19 – Dynamics of growth of the number of nodules of alfalfa and eastern galega, total number of nodules/active number of nodules, pcs./a plant, (average for 2022-2024)

It was found that the growth of the maximum number of total and active nodules was in the 'flowering' phase, which was 91 and 104 pcs./a plant in seed alfalfa and 122 and 117 pcs./a plant in eastern galega.

It is important to note that the total number of nodules in the eastern galega was higher than in the sowing alfalfa by 25%, since the galega crops fully showed their biological characteristics, namely the creation of a favourable microclimate due to the aboveground vegetative mass, which provides sufficient moisture and lowering the temperature in the crops, which allows the symbiotic apparatus of the culture to germinate more actively.

Also, in our research, we paid attention to the amount of symbiotic nitrogen formed during the 'flowering' phase of the studied crops (Fig. 20).

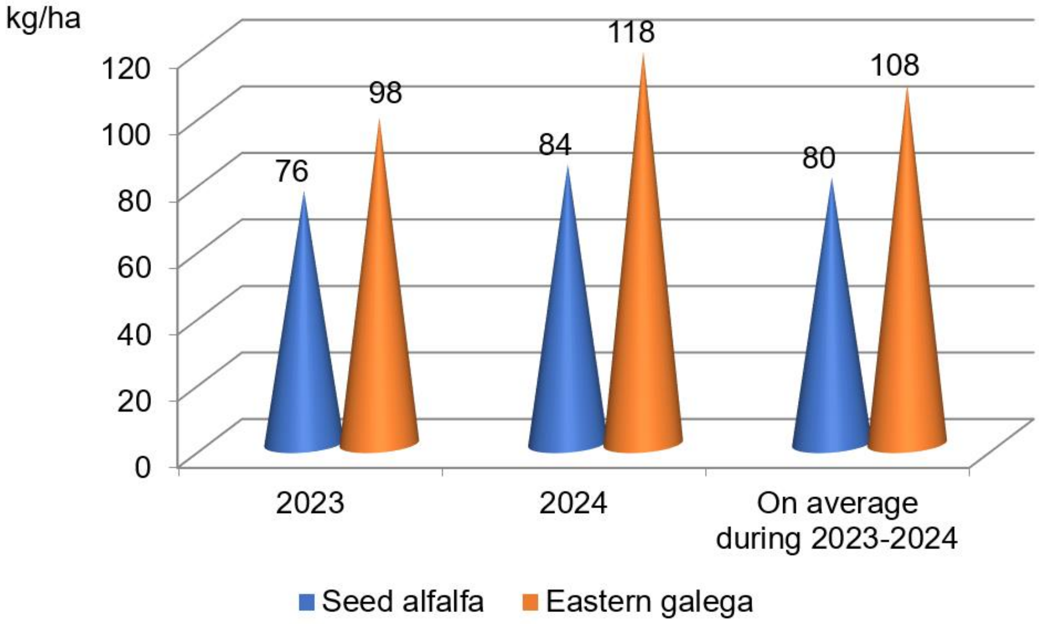


Fig. 20 – Symbiotic nitrogen growth of seed alfalfa and eastern galega in the ‘flowering’ phase, kg/ha

Our research has shown that in 2023, 76 kg/ha of symbiotic nitrogen was formed in the flowering phase of alfalfa, while in eastern galega this figure was higher – within 22.4%.

In 2024, the studied indicator was 84 kg/ha in alfalfa, which was 28.8% lower than in the plots of eastern galega.

On average, over the years of research, the amount of symbiotic nitrogen was 80 kg/ha in alfalfa and 108 kg/ha in eastern galega, which was 28 kg/ha higher.

Accordingly, we can conclude that the amount of biological nitrogen will be higher when growing eastern galega, which will allow growing environmentally friendly crops in crop rotation and save on mineral fertilisers, primarily nitrogen fertilisers.

One of the most important indicators of crop research is yield (Fig. 21).

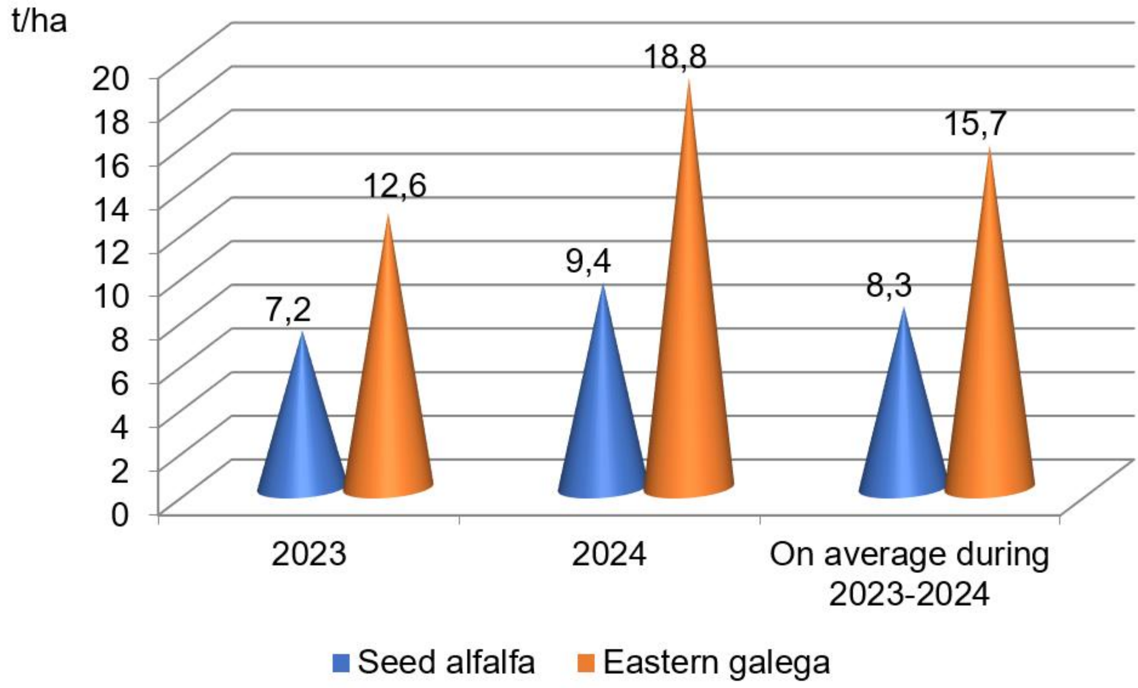


Fig. 21 – Seed alfalfa and eastern galega yields, t/ha

According to the results of the research, we can conclude that the yield of eastern galega was higher compared to eastern alfalfa. Thus, in 2023, the yield of alfalfa was within 7.2 t/ha, while the yield of eastern galega was 12.6 t/ha, which was 5.4 t/ha higher. Yields in 2024 were higher than in 2023 by 23.4-32.9%, respectively, by crops. On average over the years of research, it was found that the yield of galega was higher compared to alfalfa by 47.1%, which indicates better qualifying properties of eastern galega, respectively, which means more post-harvest and root residues remaining after mowing; also, due to the greater number of nodule bacteria, the crop managed to form a larger vegetative mass, which will allow more symbiotic nitrogen to remain in the soil after harvesting.

1.1.3.3. Ecological impact of the studied crops on agroecological indicators of soil

Soil is a system that meets the needs of plant organisms for nutrients and water, is a habitat, and provides the root system with the necessary amount of air and heat for full growth and development. Crop yields also depend on the quality of soil.

As a result of our research, we found out how seed alfalfa and eastern galea affected the agro-ecological indicators of the soil.

One of the most important indicators responsible for soil fertility is humus.

As our research has shown, the humus content depended on the crop grown in favour of eastern galega (Fig. 22).

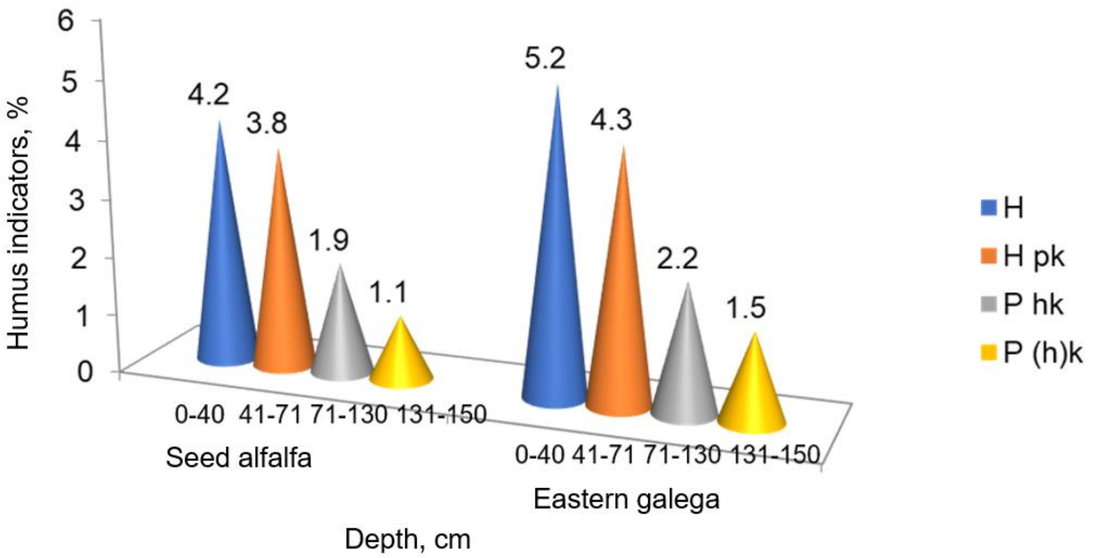


Fig. 22 – Indicators of humus content depending on seed alfalfa and eastern galega (average for 2022-2024), %.

It was found that when growing alfalfa, the sowing humus indicators were lower compared to the variants where eastern galega was grown along the horizons, depending on the depth. Thus, at the depth of 0-40 cm, the humus content for alfalfa cultivation was within 4.2%, while for the cultivation of eastern galega the studied indicator was 5.2%.

With increasing depth of the horizon, a decrease in the studied parameter was observed for both crops, but the advantage was for galega.

As a result of the data analysis, it was found that at a depth of 41-70 cm, the humus content was 3.8% (sowing alfalfa) and 4.3% (eastern galega).

As for the lower horizons, the indicators were almost the same. It was found that at the depth of 71-130 cm, the studied indicator was 1.9% (sowing alfalfa) and 2.2% (eastern galea), respectively. A similar trend was recorded at a depth of 131-150 cm, which was 1.1% (sowing alfalfa) and 1.5% (eastern galea), respectively.

The analysis of the data revealed that the cultivation of eastern galega restores the humified layer compared to the plots under sowing alfalfa, with a particularly noticeable effect in the topsoil.

In our research, we found out how the cultivated crops, namely alfalfa and eastern galega, affected the pH of the soil environment (Fig. 23).

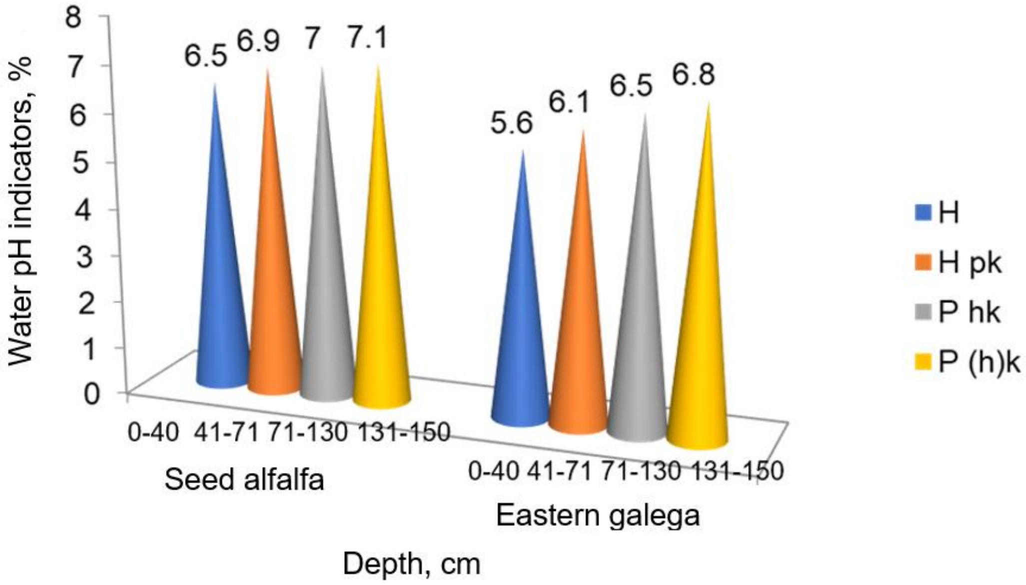


Fig. 23 – Water pH values depending on seed alfalfa and eastern galega (average for 2022-2024)

For most crops, pH close to neutral is optimal. This ensures the most positive growth and development of the root system, as well as the full provision of the nutrition process.

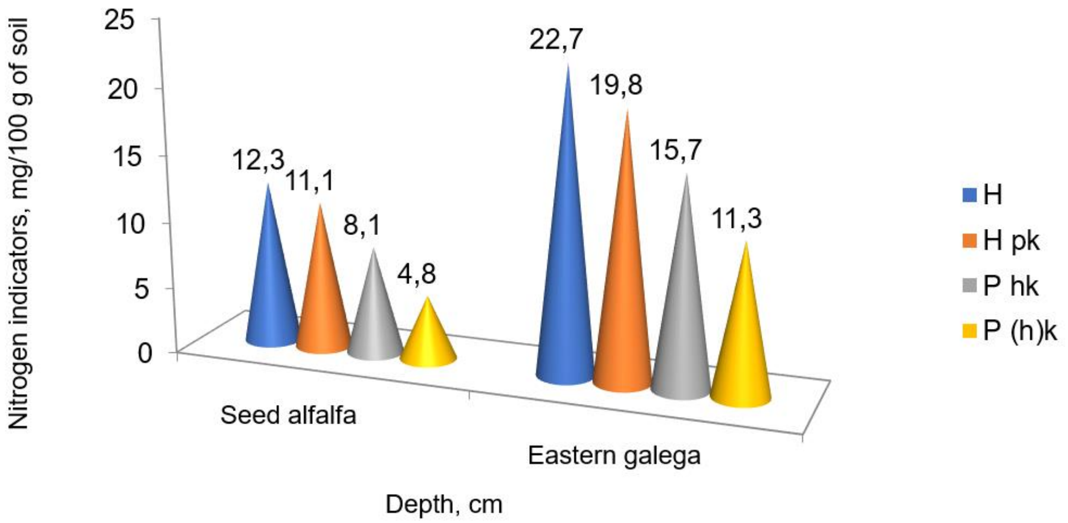
Both crops under study are legumes, which are known to raise micro- and macroelements into the upper layers of the soil due to their taproot system, which subsequently has a favourable effect on the condition of the soil itself and subsequent Our research has shown that the cultivation of both seed alfalfa and eastern galega changed the pH values deeper into the horizons.

Thus, during cultivation of sowing alfalfa, the following indicators were recorded: in the high horizon at the depth of 0-40 cm, pH was 6.5, and at the depth of 41-70 cm, pH was 6.9, while in the lower horizon, P_{hk} was pH 7.0 and $P_{(h)k}$ was pH 7.1. It was found that there was an increase in alkalinity, which will negatively affect the absorption of the following elements by plants, such as phosphorus, iron, manganese, copper, zinc, boron due to the formation of insoluble hydroxides.

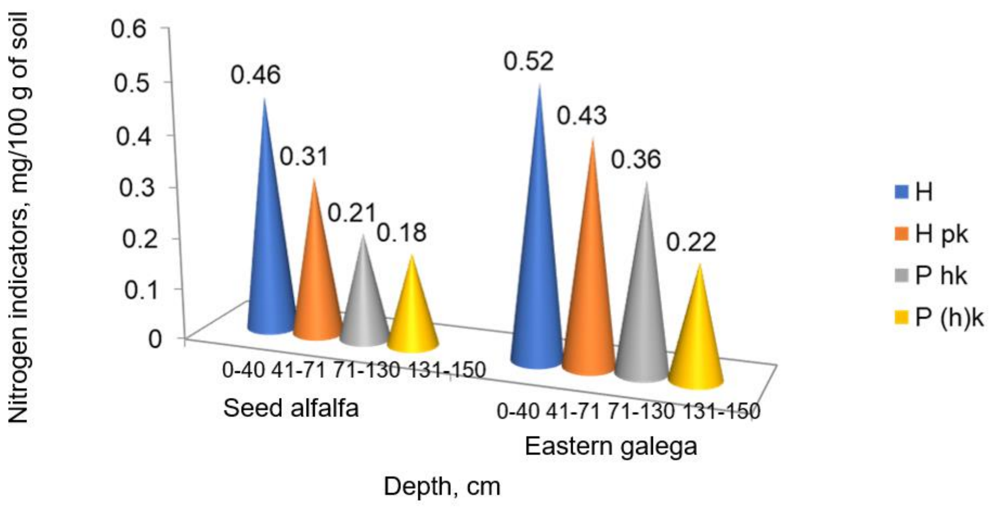
During cultivation of eastern galega, the pH of the soil medium was at the optimum level by horizons, namely: in the high horizon at the depth of 0-40 cm, the pH was within 5.6, at the depth of 41-70 cm, the pH was 6.1, while in the lower horizons, P_{hk} was pH 6.5 and $P_{(h)k}$ was pH 6.8.

Thus, the cultivation of eastern galega helps to maintain pH of the soil environment at an optimal level.

Also, in our research, we paid attention to how the cultivation of alfalfa and eastern galega affected the accumulation of nitrogen (Fig. 24).



a – alkaline-hydrolysed



b - total nitrogen

Fig. 24 – Nitrogen indicators depending on seed alfalfa and eastern galega (average for 2022-2024), mg/100g of soil

According to the results of the research, the quantitative index of alkaline hydrolysed and total nitrogen decreased along the studied soil horizons, but in the areas where eastern galea was grown compared to the areas where sowing alfalfa was grown, the indicators were higher.

At the depth of 0-40 cm in the variants where seed alfalfa was grown, alkaline hydrolysed nitrogen was 12.3 mg/100g of soil, and in the variants with eastern galega this figure was higher and amounted to 22.7 mg/100g of soil, while the total nitrogen was recorded lower and amounted to 0.45 mg/100g of soil and 0.52 mg/100g of soil, respectively.

With increasing depth, nitrogen accumulation decreased. Thus, at the depth of 41-70 cm, the studied indicator was 11.1 mg/100g of soil (seed alfalfa) and 19.8 mg/100g of soil (eastern galega) of alkaline hydrolysed nitrogen. At the same time, the indicators of total nitrogen at the same depth were 0.31 mg/100g of soil (sowing alfalfa) and 0.43 mg/100g of soil (eastern galega).

It was found that the indicators of alkaline hydrolysed nitrogen in the plots for growing alfalfa at the deth of 71-130 and 131-150 cm were 8.1 and 4.8 mg/100g of soil, respectively, and for growing eatern galega the indicators were higher, respectively, 7.6 and 6.5 mg/100g of soil.

Indicators of total nitrogen in the cultivation of seed alfalfa on the horizons P_{hk} and $P_{(h)k}$ were 0.21 mg/100g of soil and 0.18 mg/100g of soil, and in the variants where eastern galega was grown, these indicators were as follows: on the horizon P_{hk} = 0.36 mg/100g of soil and $P_{(h)k}$ = 0.22 mg/100g of soil, which was higher than in the first plots on average by 0.15 and 0.04 mg/100g of soil.

Thus, it was found that the nitrogen indicators for the cultivation of eastern galega were higher compared to the variants where sowing alfalfa was grown. This tendency was observed due to the accumulation of more organic matter and more symbiotic nitrogen accumulated in the crops of eastern galega.

In our research, we also paid attention to the accumulation of phosphorus in legume crops.

Phosphorus is absorbed by plant organisms in smaller quantities than nitrogen, although its role is also extremely important in the plant life cycle.

We found that the amount of phosphorus varied along the horizons, as well as depending on the crop under study (Fig. 25).

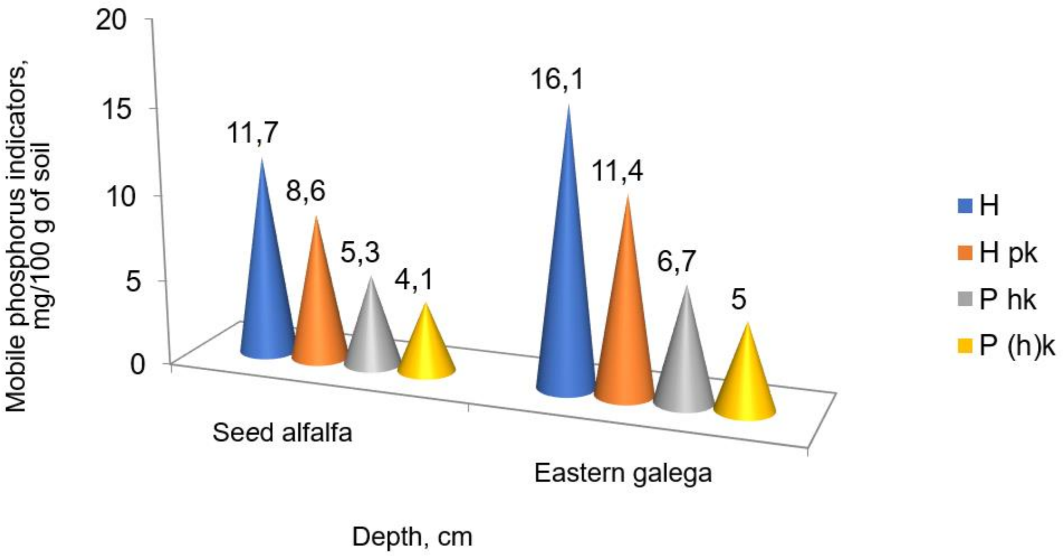


Fig. 25 – Indicators of mobile phosphorus content (according to Machyhin) depending on sowing alfalfa and eastern galega (average for 2022-2024), mg/100g of soil

With increasing depth in the horizons, the values of mobile phosphorus decreased for both crops under study.

When growing seed alfalfa, on the H-0-40 cm horizon, mobile phosphorus was 11.7 mg/100g of soil, while when growing eastern galega it was 4.4 mg/100g of soil higher.

At the H_{pk} horizon, phosphorus was within 8.6 mg/100g of soil (seed alfalfa) and 11.4 mg/100g of soil (Eastern galega), while at P_{hk} and $P_{(h)k}$, the studied indicator was 5.3 and 4.1 mg/100g of soil (seed alfalfa) and 6.7 and 5.0 mg/100g of soil (Eastern galega), respectively.

It was found that during cultivation of eastern galega there is an increase in mobile phosphorus in the soil, which exceeded similar indicators in crops of sowing alfalfa in the range of 18.0-27.3%.

We determined how the amount of potassium varied along the soil horizons (Fig. 26).

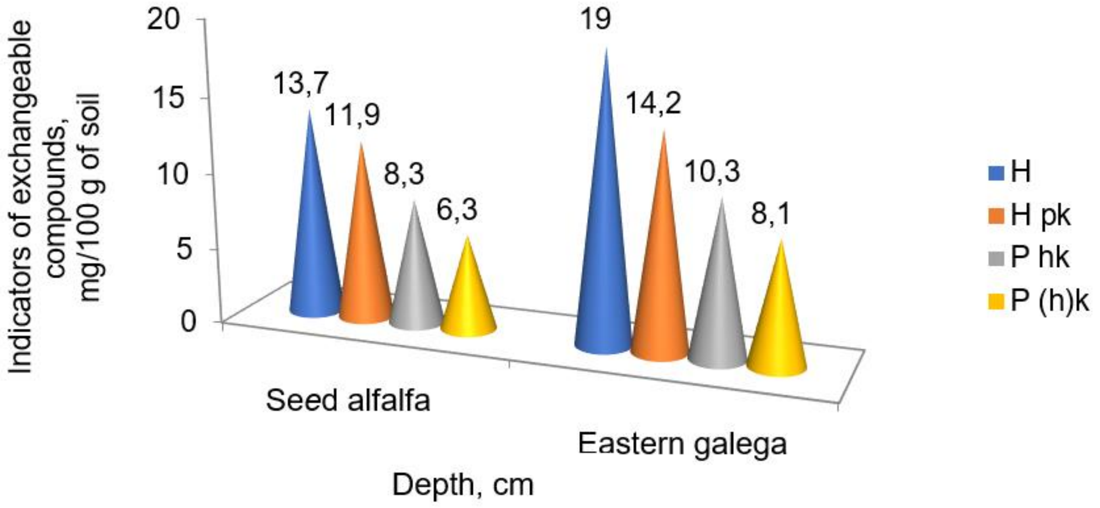


Fig. 26 – Indicators of exchangeable potassium compounds (according to Machyhin) depending on seed alfalfa and eastern galega (average for 2022-2024), mg/100g of soil

As a result of our research, it was found that the exchangeable potassium for growing seed alfalfa on the H horizon was 13.7 mg/100g of soil, while for growing eastern galega the studied indicator was 19.0 mg/100g of soil and was higher than in the previous areas within 5.3 mg/100g of soil.

It was found that, as in the study of other indicators, the indicators decreased deeper into the soil horizons.

Thus, on the H_{pk} horizon, the potassium content was 11.9 mg/100g of soil (sowing alfalfa) and 14.2 mg/100g of soil (eastern galega), while on the P_{hk} and $P_{(h)k}$ horizons, respectively, it was 8.3 and 6.3 mg/100g of soil (sowing alfalfa) and 10.3 and 8.1 mg/100g of soil (eastern galega).

It was found that the amount of exchangeable potassium was higher under the cultivation of eastern galega compared to sowing alfalfa in the range of 22.2-27.8%.

As a result of our research, it was found that the cultivation of eastern galega contributes to the reproduction of soil fertility by increasing humus, nitrogen, nitrogen phosphorus and potassium, which will have a favourable effect on the yield of subsequent crops in the crop rotation and improve the agro-ecological parameters of soil environment.

Conclusions

As a result of anthropogenic impact, namely irrational agricultural activities, the soil environment is degraded.

As a result of monoculture cultivation, there is a negative dynamics of humus and nutrient content in the soil, which leads to deterioration of agro-ecological indicators and contributes to various degradation processes.

The restoration of the soil environment and agro-ecological parameters is possible through mandatory cultivation of perennial legumes in crop rotation, which have high unifying properties, allowing to accumulate large amounts of organic matter and biological nitrogen.

1. According to the results of our research, during 2022-2024, there was a decrease in the humus content from 4.9 to 4.7%, as well as nutrients in the soil due to the cultivation of monocultures: in 2022, the indicators of nitrogen, phosphorus and potassium were 13.7, 13.4, respectively, 13.7 mg/100 g; in 2024, they were 12.9; 13.1; 13.2 mg/100 g, which were lower than the benchmark and agroecological certification data for nutrients and ranged from 12.6-42%.

2. It has been established that the cultivation of legumes leads to the accumulation of biological nitrogen. In the case of sowing alfalfa, on average, over the years of research, this figure was 80 kg/ha, while in the case of growing eastern galega it was 28 kg/ha higher.

3. Our research has shown that the yield of eastern galega was higher than that of seed alfalfa. Thus, the average yield of galega over the years of research was 15.7 t/ha, while the yield of seed alfalfa 8.3 t/ha, which was lower compared to galega within 7.4 t/ha. It has been established that eastern galega has a higher yield compared to sowing alfalfa, which, accordingly, will ensure the content of more organic matter, post-harvest residues, root residues in the soil and accumulates more symbiotic nitrogen.

4. As a result of the research, it was found that the cultivation of eastern galega leads to the accumulation of humus and nutrients on the H horizon, which provided, on average, the following indicators over the years of research: humus - 5.2 %; pH -

6.7; alkaline hydrolysed nitrogen - 22.7 mg/100g of soil, total nitrogen - 0.52 mg/100g of soil; mobile phosphorus - 16.1 mg/100g of soil; exchangeable potassium - 19.0 mg/100g of soil; and in comparison with sowing alfalfa, it was higher.

5. The following positive changes in soil environment occur during cultivation of eastern galega: soil structuring, reduction of erosion risks; accumulation of soil moisture; restoration of soil organisms, as well as an increase in soil biological activity; reduction of anthropogenic load on the soil; restoration of ecological balance.