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Growing forage grasses on the degraded lands in the Southern Steppe zone of Ukraine

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Abstract

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Intensive agricultural practices, prevalence of annual crops in crop rotations under simultaneous shrinking of sowing areas under perennial leguminous grasses and negative climate change have led to active soil degradation and desertification in the South of Ukraine. Fertility losses in degraded lands calls for immediate development of measures for the restoration of their productivity. The aim of the study was to develop technologies for growing highly productive perennial fodder grasses in conditions of insufficient natural moisture on degraded lands in the south of the Steppe zone of Ukraine. Field experiments were conducted under sowing cereal and leguminous perennial grasses with different duration of the plots conservation. In 1- to 5-year grass cultivation, sown with perennial leguminous grasses (alfalfa or sainfoin), the gross yield of absolutely dry matter reached 5.36–5.63 t/ha, the digestible protein yield was 0.84–0.97 t/ha. Under the long-term use (for 6–8 years), productivity of the herbages decreased. Seed inoculation of leguminous crops with symbiotic bacteria promotes increasing the productivity of grass stands and enrichment of the soil with nitrogen. Increasing the sowing area of leguminous grasses such as alfalfa and sainfoin, as well as their mixtures, combined with the use of new bio preparations, will help mitigate the catastrophic fertility losses and soil degradation in south of Ukraine, as well as reduce the impact of natural phenomena related to global and regional climate change.

Keywords: perennial grasses; bio preparations; soils fertility restoration

Introduction

Agricultural expansion on environment increases in the modern world. This happens on the background of negative climate change and leads to soil degradation and desertification, poses a threat for sustainable development of society. Soil degradation leads to decrease or loss of biological and economic productivity of lands in arid and dry sub-humid territories owing to various factors, including climate change and anthropogenic activity (Maestre et al., 2017). The consequences of degradation and desertification manifest themselves in the adverse changes in water balance of agro ecosystems, decrease in pasture productivity, wind and rainfall erosion, and loss of biological integrity and biodiversity (Chasek, 2022). Combating desertification and land degradation and mitigation of the consequences related to drought is able to provide for long-term socio-economic benefits for the population, living on the arid lands, and decrease their vulnerability to climate change.

The mentioned above phenomena of degradation and desertification are also observed in Ukraine, especially, in the sub-zone of the Southern Steppe. The structure of agricultural land in Ukraine has changed over the past 15–20 years, the share of cereals and legumes in the structure of sown areas has increased (54.92%), while the area under fodder crops has sharply decreased (5.86%). Therefore, significant enlargement of sowing areas under winter and spring wheat, maize, sunflower, rapeseed at the expense of cutting down the areas under perennial grasses and sugar-beets occurred. The systematic increase in arable land in Ukraine has led to unstable state of agro landscapes, and at the beginning of the XXI century, the share of arable lands here was the highest in the world. 53.8% of Ukrainian territories are under arable lands (Baliuk et al., 2021), and in the Steppe zone the score is between 79.7 and 90.2%. The transformation of the natural steppe landscapes of the Southern Steppe into a zone of stable grain production with a significant reduction in the area under fodder crops has led to global negative phenomena: intensive development of degradation processes and desertification.

Continuous and insufficiently substantiated land use under an excessive share of arable land in the Steppe zone has led to catastrophic strengthening of soil erosion (Petrychenko et al., 2020). 500 million tons of soils are lost in Ukraine per annum. Together with the by-products of erosion, up to 24 million tons of humus, 0.96 million tons of nitrogen, 0.68 million tons of phosphorus, 9.40 million tons of potassium are lost, that is, many times greater numbers than the uptake from fertilisers (Baliuk et al., 2021).

The ecological conditions of the agricultural lands of the southern part of the Steppe zone under the current economic conditions are determined by intensive plowing of land resources, leading to a decrease in water exchange between surface, and a subsurface water and sharp change in the relationship between income and uptake shares of the water balance. Most regions of the Southern Steppe suffer from critical soil moisture deficit. Additionally, a significant negative influence on the efficiency of agricultural production here is recorded due to regional climate change. Thus, in our opinion, the excessive and irrational level of agricultural expansion in the territory has led to the breakdown of the ecologically acceptable relationship between the area of arable lands, the natural forage lands, forest, and the water resources, leading to adverse effects on the sustainability of the agro landscapes and increasing their vulnerability. It should be added that negative climate change accelerates degradation and desertification processes on the lands in the South of Ukraine.

Solving the issue of fertility restoration on low-productive and degraded arable lands will favour to significant decrease in intensity of soil-degrading processes (Montanarella, 2016). Analysis of the literature testifies that in the current conditions, perennialization is growing to become more and more popular approach to improve agricultural landscapes, as it is the way of conducting agriculture under the strategic long-term inclusion of perennial crops of different types as the constituents of the improvement of agro ecosystems (Asbjornsen et al., 2013). It also foresees the exclusion of degraded land from cultivation, land conservation and perennial grasses, first of all, leguminous alfalfa (*Medicago sativa* L. or *Medicago varia* Mart.), sainfoin (*Onobrychis arenaria* Kit.), white melilot (*Melilotus albus* Medik.), medicinal melilot (*Melilotus officinalis* Pall.) and high-productive mixtures of leguminous and cereal grasses.

However, the issue of perennial herb cultivation on the degraded lands in arid climate remains almost unstudied. The purpose of this work is to develop resource-saving cultivation technologies for high-productive perennial forage grasses in the conditions of insufficient natural humidification under temporary and continuous conservation of arable lands that are excluded from cultivation in the South of Ukraine.

Materials and Methods

The field experiments were carried out at the State Research Farm named Kopani, of the Institute of Irrigated Agriculture of the NAAS of Ukraine (Kherson region). The experiments were located in the subzone of the Southern Steppe with extremely arid climate, which is characterized by high heat loss and insufficient moisture, especially in the summer. The sum of average daily temperatures above 10°C reaches 29–46°C and even more. Regional climate change in the southern steppe subzone is characterised by increased drought. Generally, during the growing season (April – September), only 150–200 mm of rainfall fell in dry years.

Experiments with the seeding of arable lands, excluded from cultivation, selection of perennial leguminous, cereal grasses, grasses mixtures, and a study of their productivity were carried out during 2010–2014, and the study of the effect of seed inoculation of leguminous grasses with symbiotic bacteria on their productivity, total and fractional content of nitrogen in soil were carried out in 2017–2020. The soil of the experimental plots was slightly alkaline dark-chestnut (Laktionova et al., 2015), with a neutral soil solution reaction (pH KCl 7.6–7.7), with a humus content (according to method developed by Tyurin) of 2.02–2.34%, phosphorus mobile forms content (according to method, described by Machigin) of 24.2–36.3, nitrogen nitrate ($N\text{-}NO_3$) of 8.0–12.3 mg/kg, and a high exchangeable potassium content of 330–413 mg/kg. The field moisture content in the 0–100 cm layer was 21.3%, the wilting temperature was 9.5%, and the bulk density was 1.42 g/cm^3. Agrochemical analyses of soil were conducted in the agrochemical laboratory of the Institute of Irrigated Agriculture of the NAAS of Ukraine.

The experimental design foresees the planting of various grasses and their mixtures (factor A), and different duration of the land conservation period (factor B): temporary short-term for 1–2 years, temporary middle-term for 2–3 years, continuous long-term for 4–5 years, continuous very long-term for 6–8 years. Sowing of arable lands was conducted using cereal and leguminous perennial grasses, which fit the most for the natural-climatic conditions of the sub-zone of the Southern Steppe. Under temporary short-term usage in mono-crops and crop mixtures annual ryegrass (*Lolium multiflorum* Lam.) cultivar Yaroslav and sainfoin (*Onobrychis arenaria* Kit.) cultivar Ingulsky were included. Under temporary middle-term usage (for 2–3 years) fescue (*Festuca orientalis* (Hack.) V. Krecz.) cultivar Dominika and alfalfa variable (*Medicago varia* T. Martyn.) cultivar Veselka were included. Under continuous long-term use of agrophytocenoses (for 4–5 years) alfalfa variable (*Medicago varia* T. Martyn.) cultivar Veselka and bromus (*Bromopsis inermis* (Loyss.) Holub) cultivar Tavriisky were included. Under continuous very long-term usage (for 6–8 years) a mixture of intermediate wheatgrass (*Elytrigia intermedia* (Host) Nevski) cultivar Vitas and alfalfa variable (*Medicago varia* T. Martyn.) cultivar Veselka was sown.

In the study of symbiotic nitrogen accumulation alfalfa variable cultivar Veselka, bromus cultivar Tavriisky, their mixture and also sainfoin cultivar Ingulsky, bromus cultivar Tavriisky and their mixture were seeded. The effect of bacterial inoculation of alfalfa seeds of the Veselka variety was studied for three years. The preparation Ecovital was used for seed inoculation, and foliar fertilisation of alfalfa crops with boron micro-fertiliser Avangard P Bor (produced by UKRAVIT, Ukraine) was additionally applied. Liquid boron fertiliser composed on the basis of organic poly-borates contained 150 g/L of boron (B), 65 g/L of nitrogen (N), and amino acids. Micro fertilizer was applied thrice at the main stages of the crop's growth and development: budding initiation, flowering initiation and massive flowering, with the dose of 1.0 L of the preparation, dissolved in 200 L of water, per 1 ha.

The sowing rate under temporary conservation of arable land at 100% plant ability in mono-crops was as follows: annual ryegrass – 24.0 kg/ha, fescue – 24.0; sainfoin – 80.0; alfalfa variable – 24.0 kg/ha, in the crop mixture, respectively, – 12, 12 and 60 kg/ha. Under continuous arable land conservation, the sowing rate for alfalfa variable in mono-crops was 24.0 kg/ha, bromus – 28.0, fescue and intermediate wheatgrass – 32.0 kg/ha. In the content of binary herb mixtures sowing rates: alfalfa variable + bromus – 12.0 + 14.0 kg/ha, and alfalfa variable + intermediate wheatgrass – 12.0 + 16.0 kg/ha. The sowing plot area was 60 m^2, accounted area was 20 m^2. Forage yield estimation was conducted using the mowing method.

Pre-sowing inoculation of alfalfa variable seeds was conducted using novel complex bacterial preparation Ecovital, developed at the D.K. Zabolotny Institute of Microbiology and Virology of the NAS of Ukraine on the basis of symbiotic nitrogen-fixing bacteria (*Sinorhizobium meliloti* UCM B-6076) and phosphorus-mobilizing bacteria (*Bacillus megaterium* UCM B-5724). The preparation contains living bacterial cells with a titre not less than $3–5 \cdot 10^9$ cells/ml, and the products of their metabolism, which possess phytostimulating and phytoprotective actions, such as group B vitamins, phytohormones (auxins, cytokinins, gibberellins), amino-, fatty-, and organic acids, polysaccharides Inoculation were conducted through pre-sowing seeds spraying with the norm of 100 ml of the preparation per ha. The pre-sowing inoculation of sainfoin seeds was carried out with the Ryzobophit preparation based on the bacteria *Rhizobium onobrichis* (producer – The Institute of Agricultural Microbilology of the NAAS of Ukraine) with a norm of 100 ml of the preparation per ha.

Changes in dry matter and protein contents in phytomass were evaluated described by Dmitrochenko (1978); contents of gross and exchangeable energy was estimated by methodology of Medvedovskii and Ivanchenko (1988). Potential evaporation (Eo) and water supply deficit (ΔEo) by the years of the study were calculated by method proposed by Ivanov (1962). The fractional content of nitrogen in the soil layer of 0–40 cm under soybean crops was determined in the field experiment in 2020 by the methodology of Shkonde and Koroleva (1964).

The estimation of fixed nitrogen volumes in the herbage of perennial leguminous grasses was carried out using the comparative method by direct comparison of nitrogen uptake by leguminous and cereal grasses. Nitrogen uptake by sainfoin was compared to corresponding indicator of annual ryegrass, and the uptake by alfalfa variable – with the uptake of bromus. The difference between nitrogen uptake with the yields of leguminous and cereal grasses, with an adjustment on the nitrogen content in the seeds, was attributed to fixed biological nitrogen. The coefficient of biological nitrogen fixation was calculated as a ratio of the volume of fixed biological nitrogen to its total uptake.

The chemical contents of the air dried herbage samples were assessed by spectrography, using an infra-red analyser NIP Systems 4500. Gross and exchangeable energy outputs were calculated by the data of chemical composition of the forages, using the coefficients of digestibility and productive action of nutritious elements by Medvedovskii and Ivanchenko (1988).

The results obtained were statistically processed with SPSS program using ANOVA post hoc Tuckey's test ($p < 0.05$) as well as T-test ($p < 0.05$).

Results

The climate of sub-zone of the Southern Steppe of Ukraine, where the field experiments were conducted, is extremely arid, with high temperature regime, especially in the summer period of growing season. The sums of average daily temperatures above 10°C reached 29–46°C. The amount of rainfall was extremely low (from 154.2 to 285.9 mm), that created a deficit in crops water supply, which reached 472.4–757.4 mm.

Evaluation of the herbage productivity showed that under the short-term conservation of arable lands, excluded from cultivation, the yield of absolutely dry matter in the mono-crops of annual ryegrass was 4.95 t/ha; the herbage contained 0.67 t/ha of digestible protein; 87.9 GJ/ha of gross, and 50.8 GJ/ha of exchangeable energy (Table1).

In sainfoin crops and ryegrass-sainfoin mixtures, the absolute dry matter yield was higher than in the mentioned crop by 13.7% and 13.5%, respectively, while the digestible protein yield was 25.4 and 35.8%. Gross energy of the herbage was higher than in ryegrass mono-crops by 14.3–14.4%, and exchangeable energy – by 6.4–6.7%.

Under the temporary middle-term conservation of arable lands the yield of absolutely dry matter in the mono-crops of fescue was not higher than 4.16 t/ha, the yield of digestible protein – 0.41 t/ha. The gross energy of the herbage was 75.5 GJ/ha, and the exchangeable energy was 43.0 GJ/ha. The yields of alfalfa mono-crops and fescue-alfalfa mixtures surpassed the mono-crops of fescue by 33.7–34.9%; the yields of digestible protein were 92.7–107.3% higher; the gross energy output was higher by 35.6–36.7%, and the output of exchangeable energy – higher by 36.0–37.2%.

In the cultivation of forage grasses under continuous long-term conservation, the yield of absolutely dry biomass was not inferior to that under temporary conservation. It should be mentioned that compared to bromus, the crops of alfalfa and mixtures of bromus and alfalfa showed higher indicators of dry mass − 19.9–23.9%, digestible protein − 95.7–110.9%, gross and exchangeable energy − 22.5–25.9%.

The lowest yield was obtained by cultivating grasses in continuous very long-term (for 6–8 years) land conservation.

Table 1. Productivity of the perennial grasses and their mixtures under temporary and continuous conservation of arable lands, excluded from cultivation (average for 3 years of the study)

Species and crop mixtures	Yield per 1 ha			
	Absolutely dry matter, t	Digestible crude protein, t	Gross energy, GJ	Exchangeable energy, GJ
Temporary short-term (for 1–2 years)				
Annual ryegrass	4.95^{a}	0.67^{a}	87.9^{a}	50.8^{a}
Sainfoin	5.63^{b}	0.84^{b}	100.5^{b}	58.1^{b}
Ryegrass-sainfoin mixture	5.62^{b}	0.91^{c}	93.8^{c}	54.1^{c}
Temporary middle-term (for 2–3 years)				
Fescue	4.16^{c}	0.41^{d}	75.5^{d}	43.0^{d}
Alfalfa	5.61^{b}	0.85^{b}	103.2^{b}	59.0^{b}
Fescue-alfalfa mixture	5.56^{d}	0.79^{e}	102.4^{b}	58.5^{b}
Continuous long-term (for 4–5 years)				
Bromus	4.47^{e}	0.46^{d}	81.8^{e}	47.2^{e}
Alfalfa	5.36^{f}	0.97^{f}	100.6^{b}	57.8^{b}
Bromus-alfalfa mixture	5.52^{d}	0.90^{c}	103.0^{b}	59.2^{b}
Continuous very long-term (for 6–8 years)				
Intermediate wheatgrass	3.24^{g}	0.41^{d}	59.0^{f}	33.8^{f}
Alfalfa	3.30^{h}	0.62^{a}	61.6^{g}	35.2^{f}
Wheatgrass-alfalfa mixture	3.33^{h}	0.59^{g}	61.7^{g}	35.0^{f}

$^{a-h}$ – values for the same parameter, different years and different species, marked with different letters have statistically significant differences ($p < 0.05$), ANOVA post hoc Tuckey's test.
Source: Authors' own elaboration

In such conditions, the yield of absolutely dry matter was within 3.24 – 3.33 t/ha, the yield of digestible protein was 0.41–0.62 t/ha, and the output of exchangeable energy was 33.8–35.2 GJ.

Significant decrease ($p < 0.05$) in the yields of absolutely dry matter of the third year of use is connected to the change in species both of mono-crops of alfalfa and sainfoin, and alfalfa- and sainfoin-cereal mixtures. Preservation of high productivity in the herbage of leguminous and cereal grasses and their mixtures was real just under the constant use of high-productive grassland species of plants.

Therefore, the maximum yield ($p < 0.05$) of digestible protein during all the years of the use of perennial grasses was obtained in the mono-crops of alfalfa, inoculated with Ecovital, and also in the binary alfalfa-cereal herb mixtures. The use of the microbial preparation improved the resistance of the plants to adverse environmental factors, and activated the process of nitrogen biological fixation.

Symbiotic fixation of atmospheric nitrogen by rhizobium-plant systems in sainfoin and alfalfa guaranteed nitrogen accumulation in the soil. In the first year of herbage use, the accumulation of symbiotic nitrogen in the mono-crop alfalfa reached 60 kg/ha, and in the crop mixture alfalfa + bromus – 68 kg/ha, while the nitrogen fixation coefficient was averaged at 33.5% and 36.4% (Table 2). The fixation of atmospheric nitrogen in the mono-crops of alfalfa and in the herb mixture was equivalent to 174–198 kg/ha of nitrogen from ammonium nitrate or 15.1–17.2 GJ/ha of gross energy. In the second year of the herbage use, the accumulation of symbiotic nitrogen by alfalfa and herb mixture was also high – 37–55 kg/ha at the nitrogen fixation coefficient 23.7–31.6%. Atmospheric nitrogen fixation by alfalfa in the mentioned above amounts was equivalent to 107 – 160 kg/ha of mineral nitrogen, or 9.3–13.9 GJ/ha of gross energy. In the third year of herbage use, the accumulation of biological nitrogen by alfalfa and crop mixture decreased to 36–37 kg / ha, which is related to the change in the species of the sown grasses and the consecutive decrease in the share of alfalfa in the mixture. Similar regulation was observed in the crops of sainfoin and its mixtures with ryegrass.

In the mono-crop herbage and the crop mixture of the first year of use the coefficient of nitrogen fixation averaged to 32.9–34.1%, and biological nitrogen fixation was 53–56 kg/ha, which is equivalent to 154–162 kg/ha of mineral nitrogen, or 13.4–14.1 GJ/ha of gross energy. In the second year, the use of atmospheric nitrogen by sainfoin was also high that provided for nitrogen accumulation in the soil up to 63–68 kg/ha, which is equivalent to 183–194 kg/ha of nitrogen from ammonium nitrate or 15.9–17.1 GJ/ha of gross energy, the nitrogen fixation coefficient was 35.9–37.0%. In the third year of the sainfoin use, the accumulation of symbiotic nitrogen, comparing to previous years, decreased 1.6–2.1 times in the mono-crops, and 1.6–1.8 times in the mixture. This is due to the great decrease in the share of sainfoin in mono-crops and the mixture.

A significant ($p < 0.05$) positive effect on nitrogen fixation and biomass accumulation in sainfoin crops was provided by seed inoculation before sowing with Ryzobophit preparation symbiotic bacteria (Table 3). In the mono-crop, the dry biomass yield of the inoculated sainfoin surpassed the control by 17%, and in the mixture – by 9.6%. In the biomass of inoculated sainfoin, the digestible protein content under inoculation was greater by 4.2%, and in the herb mixture by 5.2%. The increase in the exchangeable energy output under inoculation was greater by 7.2% in comparison to the control.

Investigation of fractional nitrogen content in soil determined the positive effect of inoculation on the content of mineral and mobile nitrogen compounds. It is known that

Table 2. Symbiotic nitrogen accumulation by alfalfa and sainfoin depending on the year of the Herbage usage

Nitrogen in arvest and symbiotic accumulated	Alfalfa	Alfalfa + bromus	Bromus	Sainfoin	Sainfoin + ryegrass	Ryegrass
1 year of usage						
1*	179	187	110	161	164	108
2**	60	68	0	53	56	0
2 year of usage						
1*	174	156	119	184	179	116
2**	55	37	0	68	63	0
3 year of usage						
1*	150	151	114	160	152	106
2**	36	37	0	32	34	0

Note: 1* – Nitrogen output with harvest, kg/ha; 2** – Symbiotic Nitrogen accumulated, kg/ha

Source: Authors' own elaboration

the fraction of mineral nitrogen contains ammonium and nitrate compounds, which are available for plants uptake. The fraction of mobile nitrogen includes nitrates, nitrites, ammonium, amides, amino acids, and amino-sugars, etc. These compounds are also easily available for plants uptake through their mineralization by the roots' secrets and soil microbiota. These fractions are the main reserve for plants nitrogen nutrition.

The experiment showed that three years of alfalfa cultivation under the treatment of its seeds with Eco vital favoured to the accumulation of total nitrogen in the soil, including those compounds, which are readily available for the uptake by plants (Table 4). Comparing to the non-inoculated plants, the content of total nitrogen in the soil layer 0 – 20 cm increased by 1.6 – 3.1% regardless fertilisation regime.

It is important to stress that in the soils, covered with inoculated alfalfa, the contents of nitrogen fractions, available for plants uptake, increased. The highest ($p < 0.05$) content was under seeds inoculation with Eco vital and foliar application of boron fertilisers. In this variant, the content of nitrate and ammonium salts (mineral nitrogen fraction) increased ($p < 0.05$) in soil layers 0–20 and 20–40 cm by 20% compared to the control with no preparations applied; the content of mobile nitrogen compounds increased ($p < 0.05$) by 10.1–11.2%, respectively.

Determination ($p < 0.05$) of the fractional nitrogen contents in the soil layers 0 – 20 and 20 – 40 cm after three years of alfalfa use testifies that comparing to other links of the crop rotation, it had the highest amount and, depending on the soil layer, averaged to:, total – 1006.3 and 1428.8 mg/kg, respectively; mineral – 24.9 and 46.3; mobile – 113.8 and 186.0; hardly mobile – 155.5 and 214.4; immobile – 712.1 and 982.1 mg/kg of the soil (Table 5).

The high contents of mineral and mobile nitrogen in the dark-chestnut soil under the cultivation of alfalfa allow accumulating the pool of nutritious elements for further crops (cereals, winter rapeseed, sunflower), without the application of mineral nitrogen fertilisers under conditions of in-

Table 3. Effect of sainfoin seeds inoculation with Ryzobophit on the biomass accumulation and its forage quality

Species and crop mixtures	Yield of the absolutely dry biomass, t/ha	Digestible protein, t/ha	Exchangeable energy, GJ/ ha
Pre-sowing seeds inoculation by Ryzobophit			
Sainfoin	6.34[a]	0.74[a]	65.3[a]
Ryegrass	4.38[a]	0.57[a]	52.2[a]
Ryegrass + sainfoin	6.49[a]	0.81[a]	59.5[a]
No pre-sowing seeds inoculation			
Sainfoin	5.42[b]	0.71[a]	60.9[b]
Ryegrass	4.36[a]	0.57[a]	52.3[a]
Ryegrass + sainfoin	5.92[b]	0.77[b]	59.3[a]

[a, b] – values for the same species, same parameter, but different pre-sowung inoculation, marked with different letters have statistically significant differences ($p < 0.05$), T-test.
Source: Authors' own elaboration

Table 4. Effect of alfalfa seeds inoculation with Ecovital on the fractional contents of nitrogen in soil

Boron fertilisers	Soil layer, cm	Total nitrogen, mg/kg	Contents of nitrogen compounds, mg/kg of the soil			
			mineral*	mobile	hardly mobile	immobile
Pre-sowing seeds inoculation with Ecovital						
No fertilisers	0–20	1247.1[a]	39.7[a]	134.7[a]	177.0[a]	895.8[a]
	20−40	917.3[a]	23.6[a]	97.7[a]	137.6[a]	658.5[a]
Avangard P Bor	0–20	1248.7[a]	44.6[b]	139.3[b]	196.2[b]	869.6[b]
	20−40	940.5[b]	21.5[b]	99.0[b]	152.1[b]	668.0[b]
Boron pre-sowing seeds inoculation						
No fertilisers	0–20	1209.7[a]	38.8[a]	132.6[a]	174.8[a]	836.45[a]
	20−40	883.4[a]	18.5[a]	87.7[a]	129.07[a]	648.2[a]
Avangard P Bor	0–20	1228.7[b]	43.6[b]	129.3[b]	196.2[b]	869.6[b]
	20−40	940.5[b]	21.5[b]	99.0[b]	152.1[b]	668.0[b]

**Note*: mineral nitrogen – (N –NO_3+N–NH_4).
[a, b] – values for the same parameter at the same pre-sowing and the same soil layer, between different fertilizing methods, marked with different values have statistically differences ($p < 0.05$), T-test.
Source: Authors' own elaboration

Table 5. Fractional nitrogen contents in the links of the crop rotation at the State research Farm Kopani of the Institute of Irrigated Agriculture of NAAS

The link of the crop rotation	Soil layer, cm	Total nitrogen, mg/kg	Fractional contents of nitrogen, mg/kg			
			mineral*	mobile	Hardly mobile	immobile
Alfalfa	0–20	1428.8[a]	46.3[a]	186.0[a]	214.4[a]	982.1[a]
	20–40	1006.3[a]	24.9[a]	113.8[a]	155.5[a]	712.1[a]
Winter wheat	0–20	1176.0[b]	19.2[b]	121.2[b]	179.7[b]	855.9[b]
	20–40	892.0[b]	21.1[b]	95.1[b]	132.6[b]	643.2[b]
Sunflower	0–20	1123.0[c]	22.3[c]	110.7[c]	168.4[c]	821.6[c]
	20–40	834.0[c]	12.6[c]	81.6[c]	127.1[c]	612.7[c]
Fallow field	0–20	1231.0[d]	39.4[d]	146.4[d]	170.8[d]	874.4[d]
	20–40	917.0[d]	25.1[a]	99.5[d]	134.3[b]	658.1[d]

**Note*: mineral nitrogen – (N –NO_3+N–NH_4).
[a, b, c, d] – values for the same parameter and the same soil layer, but different crops, marked with different letters have statistically significant differences ($p < 0.05$), ANOVA post hoc Tukey's test.
Source: Authors' own elaboration

sufficient natural humidification. Thus, expansion of areas under alfalfa in the combination with complex inoculation is one of the most effective measures to cope with the difficulties, which arose in the recent decades in small stakeholders and private rural farms of the Southern Steppe of Ukraine.

So, restoration of the fertility of the degraded dark-chestnut soil was achieved through long-term use of drought-tolerant species of perennial leguminous grasses (alfalfa and sainfoin), which are highly adaptable to natural-climatic conditions of the sub-zone of the Southern Steppe. High productivity of alfalfa and sainfoin mono-crops, inoculated with bacterial preparations, was obtained in the southern zone of the steppe under conditions of insufficient moisture supply.

Discussion

The task of restoring soil fertility on degraded land attracts the attention of many scientists (Issoufou et al., 2020; Kong et al., 2021; Lal, 2015; Saturday, 2018). Generalising the methods of restoring degraded ecosystems and combating desertification on arid lands, it should be admitted that they are mainly based on the cultivation of vascular plants (Maestre et al., 2017). Most scientists, who are involved in this problem, are in favour of cultivating perennial grasses over annual ones. It is emphasised that the inclusion of perennial grasses in crop rotations for soil fertility restoration and the retention of nutritious elements is based on ecological theory and long historical practise (Mosier et al., 2021). There are different crops used for perennial cultivation. The data of Mosier et al. (2021) testifies that in the Michigan State (the US boarders with Canada) in the conditions of perennial cropping systems the yield of green biomass, obtained in the 6-year course, averaged to (Mg ha^{-1}): switch grass (Monoculture switch grass) – 8.5 ± 0.4, miscanthus (Monoculture miscanthus) – 21.9 ± 0.3, wild-grasses mixture – 6.5 ± 0.9. So, the yield under the conditions of moderate climate was slightly different from our results, obtained under arid climate and insufficient rainfall. It should be stressed that perennial legumes, which are favourable to nitrogen enrichment of soil, were not cultivated in the quoted study. The root residuals of alfalfa and red clover, as well as other leguminous grasses are known to accumulate a sufficient amount of nitrogen for further cereal crops. That is why crop rotations with perennial legumes have lower requirements to mineral fertilisation and possess higher rates of nitrogen and carbon accumulation in soils (Morris et al., 1993, Gregorich et al., 2001). The positive effects of sainfoin cultivation are reported for degraded land in Turkey (Sariyildiz and Savaci, 2020). It was found that sainfoin cultivation improves soil productivity by increasing soil organic matter, improving soil structure, and increasing field capacity and soil nutrient retention. However, most studies lack application of microbial preparations for seed inoculation in leguminous crops (Trivedi, 2017).

The results of our study testify to about the high potential for soil enrichment in biologically fixed nitrogen in the crops of alfalfa and sainfoin under the previous pre-sowing inoculation of their seeds with specific strains of symbiotic bacteria. To increase arable lands fertility and provide for existing animal husbandry with forage it is required to increase sowing areas under perennial grasses.

Conclusions

Increase in the areas of mono-crops of perennial leguminous grasses – alfalfa and sainfoin – and their cereal–leguminous crop mixtures, combined with the application of novel microbial preparations, allows removing catastrophic losses of fertility and degradation of the soils of the Southern Steppe of Ukraine, decreases anthropogenic loads on agricultural lands, reduces the negative influence of natural phenomena related to global and regional climate change, and provides cereal, industrial and vegetable crops with the best fore-crops.

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Declaration of competing interests

The author declares no conflict of interest.

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