NARDI FUNDULEA, ROMANIA ROMANIAN AGRICULTURAL RESEARCH, NO. 42, 2025
www.incda-fundulea.ro; doi.org/10.59665/rar4248 First Online: April, 2025. DII 2067-5720 RAR 2025-85

Green Manure: a Sustainable Solution for Enhancing Fertility and Reducing Acidity in Albic Luvisols of Northwestern Romania

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ABSTRACT

In recent years, the shift towards sustainable agriculture has gained momentum. With climate change posing new challenges, adopting innovative farming strategies is essential. One effective approach is replacing excessive nitrogen fertilizers with green manures, which not only serve as natural fertilizers but also enhance soil health, boost organic carbon levels, support beneficial microbiomes, improve water retention, and offer numerous other benefits to the soil.

This study explores the effects of green and chemical fertilizers on the acidic albic luvisols of northwestern Romania, focusing on enhancing soil fertility, reducing acidity, and improving agricultural productivity. Field experiments involving wheat, sunflower, and maize were conducted to evaluate the combined impact of green manure crops (rapeseed, sunflower, soybean, pea, and triticale) and chemical fertilizers.

Results indicated a significant improvement in soil properties, including increased organic carbon, nitrogen, and humus levels. Wheat yielded an 18% productivity increase, sunflower by 15%, and maize by 31% under combined fertilization compared to control. The findings affirm the potential of integrating green and chemical fertilizers as a sustainable strategy for optimizing soil health and boosting crop yields in challenging soil conditions.

Keywords: green manure, soil fertility, acidic soils, sustainable agriculture, crop productivity.

INTRODUCTION

Green manures are made up of certain plants that are cultivated for the purpose of incorporating them into the soil along with the basic works. The plants used as fertilizer must produce as rich a vegetable mass as possible, in the shortest possible time, and must not be pretentious to the soil. The plants used for this purpose are mostly legumes (lupin, peas, forage peas) but other plants can also be used, such as rye, sunflower, rapeseed, mustard and others (Dumitru et al., 2003). Pollution caused by N fertilization in agriculture, has become a global problem that is difficult to solve (Martinez-Dalmau et al., 2021). Modern high input–based intensive cropping systems often lead to the deterioration of the soil environment (Zhang et al., 2022). Crop yield typically increases with N fertilizer application until a maximum yield level is reached. Beyond this point, a further increase of N application rate will reduce crop yield (Ren et al., 2022).

Research carried out in Romania on acidic soil from Livada area, in the interval 1991-1993, demonstrated that the contribution of green fertilizers (lupine) to the improvement of the agrochemical indices of the soil and to the realization of productions is at the level of the use of fertilization with 20 tons/ha of animal manure (Sîrca, 1997).

In order to increase the green mass and, at the same time, bring the action closer to that of the animal manure, it is necessary that when sowing plants used as green manure, phosphate fertilizers should be introduced into the soil, and potassium salts should be added to the sandy soils (Davidescu and Davidescu, 1981).

Soil is a resource that recovers very slowly, being represented by the loosened

Received 11 December 2024; accepted 9 April 2025.

layer from the earth's surface which, under the continuous and long-term action of atmospheric agents and successive plant formations, in specific conditions of the geographical environment, has accumulated the elements of fertility, being thus able to maintain higher plant life (Şerban, 2014).

Biological nitrogen fixation is an alternative source of fertilizer for the development of sustainable agriculture (Takil and Kayan, 2023).

The basic element of fertility, humus is considered to be one of the most complicated substances on earth, it is a mixture of organic substances resulting from the death of living microorganisms and plant and animal remains. Scientifically speaking, it is known that in the soil layer with a thickness of one meter on an area of one hectare there are on average 290 tons of humus, 15 tons of nitrogen, 19 tons of phosphorus, 204 tons of potassium, as well as an important amount of microelements: copper, zinc, manganese, molybdenum, etc. Vegetable species feed on soil, air and water, a process in which the roots participate, with the help of which the plants take water and the necessary mineral substances from the soil solution (nitrogen, phosphorus, potassium, calcium, magnesium, iron, copper, boron); the green parts of the plant (leaves, shoots), with the help of which the plant captures solar radiation, absorbs C dioxide and, through chlorophyll, forms the complex substances necessary for life (Şerban, 2014).

Although its applicability is limited, but especially occasional in time, soil treatment with green plant residues represents one of the measures with great soil improvement value. Due to its rich content in energetic material and nutrients, green plant residues represent an important means of stimulating soil microflora. In addition, it should be remembered the special role of green manure in improving physical properties such as: soil porosity and structure, the basic elements in the set of factors of a biotic environment (Eliade et al., 1975). Soil organic matter is the only source of nitrogen in the soil; it also contains other nutrients, especially sulfur and phosphorus. It has an important role in the formation of soil structure, in the retention and release of nutrients in thermal and aeration processes and implicitly in soil fertility (Ștefan, 2000). The use of conservative soil maintenance systems, respectively the mulching systems and the cover crops, caused changes (quantitatively and qualitatively) on the biodiversity of soil (Șerdinescu et al., 2023).

Such an ecosystem combines the advantages arising from the intense participation of legumes in crop rotation: the enrichment of the physical, chemical and biological conditions of the soil, the deep loosening through their strongly developed deep root system, the supply of phosphorus and calcium from the depth to the surface along with the enrichment of the soil in biological nitrogen without reducing production volume (Ionescu et al., 1978).

MATERIAL AND METHODS

The aim of this experiment was to evaluate the effects of green manures, both independently and in conjunction with chemical fertilizers, on soil fertility, acidity, and overall soil health, as well as their impact on the cultivation of wheat, sunflower, and maize. The study involves a comprehensive assessment of key parameters, including crop yield for winter wheat, sunflower and maize crops, the interaction between green manures and chemical fertilizers on soil pH levels, and the influence on essential soil components such as total nitrogen (N total), organic carbon (C organic), and humus content.

The experience was carried out at the experimental fields of the Livada Agricultural Development Research Station, which are located at the geographical coordinates of 23°03′ longitude and 47°54′ latitude, having an altitude of 130 m. The prevailing soils in this area are characterized by a predisposition to water stagnation due to a B horizon, with a clay content of 30-40%. Also, the presence of aluminum ions requires the periodic application of amendments to correct the soil acidity (Vista et al., 2024). Albic luvisols are argililoluvial soils that form especially in temperate zones, characterized by an intense process of clay elution and accumulation in the lower horizons, being frequently associated with forest vegetation (Florea and Munteanu, 2012). These soils show a characteristic sequence of horizons, including an albic horizon (E), which is highlighted by the loss of iron oxides and clay, resulting in a light coloration (IUSS Working Group WRB, 2015).

Albic are acidic soils, having a slightly acidic to acidic pH and a low content of exchangeable bases, which limits the soil's natural fertility. Low humus content, caused by the presence of fulvic acids, is a common feature, negatively influencing soil structure and nutrient availability (Manea et al., 2009). Their compact structure in the Bt horizon can cause water stagnation, which requires interventions to ensure adequate drainage (Florea and Munteanu, 2012). Regarding average temperatures, the 2022/2023 season was characterized by higher values than the multiannual average in most months, with significant differences in January (+6.8°C), August (+3.1°C) and September (+4.5°C), indicating a trend towards milder winters and warmer summers. The exception is April, which was 0.9°C below the multiannual average (Table 1).

In the 2023/2024 season, temperatures continued to rise from the multi-year average, with the largest difference recorded in February (+7.4°C). These variations indicate a climate warming trend, especially in the winter and mid-summer months.

In terms of precipitation, the 2022/2023 season had an annual total below the multi-year average by 40 mm, with significant deficits in May (-56 mm), June (-20.6 mm) and August (-30 mm), which indicates a dry summer. However, there were also months with excess precipitation, such as November (+22.6 mm) and December (+49.5 mm), showing an uneven seasonal distribution (Table 1).

The 2023/2024 season had an annual total higher than the multi-year average by 81.7 mm, with notable increases in November (+72.5 mm), December (+64.3 mm) and June (+56.4 mm), reflecting an increase in precipitation in the cold season and early summer. However, significant deficits in July (-53 mm) and August (-59 mm) confirm a drought trend in mid-summer. This climate variability can negatively influence agriculture, especially during critical months for crop development (Table 1). The small amounts of precipitation corroborated with the high temperatures, led to a marked decrease in the values of the soil accessible moisture (Zaldea et al., 2023).

The table thus highlights an increasingly unstable climate, with rising temperatures and an uneven distribution of precipitation, phenomena associated with climate change and requiring adaptations in agricultural management strategies (Table 1).

Table 1. The average temperature and amount of precipitation

Year	Climatic factor	Month												Average temperature (°C)	Total precipitation (mm)
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.		
2022/ 2023	Temperatures (°C)	12	6.2	3.1	4.8	1.5	6.4	9.6	16.3	19.7	22.2	23	20	12.05	
	Multiannual	9.8	4.8	0.1	-2	0.1	4.7	11	15.8	19	20.5	19.9	15.5	9.89	
	The difference±	2	1.4	3	6.8	1.4	1.7	-0.9	0.5	0.7	1.7	3.1	4.5	2.16	
	Precipitation (mm)	29	78.8	111	69	66	46	73	19.7	70.2	62.2	43.9	40.2		709.7
	Multiannual	54	56.2	61.8	49	44	46	51	75.5	90.8	80.8	74.3	66		749.7
	The difference±	-25	22.6	49.5	20	22	0.1	22	-56	-20.6	-19	-30	-26		-40
2023/ 2024	Temperatures (°C)	13	5.9	3	1.4	7.5	9.3	13	17.4	21.3	24.4	23.5	18.7	13.2	
	Multiannual	9.8	4.8	0.1	-2	0.1	4.7	11	15.8	19	20.5	19.9	15.5	9.89	
	The difference±	3.5	1.1	2.9	3,4	7.4	4.6	2.6	1.6	2,3	3.9	3.6	3.2	3.34	
	Precipitation (mm)	65	129	126	76	42	40	42	30.2	147	27.6	15.7	91.6		831.4
	Multiannual	54	56.2	61.8	49	44	46	51	75.5	90.8	80.8	74.3	66		749.7
	The difference±	11	72.5	64.3	27	-2.7	-5.7	-9.3	-45	56.4	-53	-59	25.6		81.7

This experiment included three main crops: wheat, sunflower and maize, to which the same experimental method was applied, using identical variants. For each crop, the cultivation technology specific to the Livada area and the northwestern region of Romania was respected, adapted to the local pedoclimatic conditions and the specific requirements of each cultivated plant.

The experiment was set up according to the method of split plot design, with three replications, and included two main experimental factors. Factor A is represented by the plant species used as green fertilizers A1 - Control (without green fertilizer), A2 - rapeseed; A3 - sunflower; A4 - soybean; A5 - peas; A6 - triticale. They were sown in June, immediately after the barley harvest, and incorporated into the soil in a green state in autumn, approximately in the flowering phenophase. The B factor is represented by fertilizers, with two gradations, B1 - chemically fertilized and B2 - chemically unfertilized. Calcium ammonium nitrate (27% N) was used as a chemical fertilizer in this experiment, 450 kg/ha in the case of wheat and 400 kg/ha in the case of spring crops. In the case of the wheat crop, it was applied in two phases, 225 kg in the fall and 225 kg in the spring and for maize and sunflower 400 kg before sowing.

RESULTS AND DISCUSSION

Fertilization with mineral fertilizers positively influences dry matter production. (Naie et al., 2024). The results obtained show that peas were the most efficient species in first year (2023), with significant amounts of nitrogen left in the soil, contributing 471.74 kg/ha, due to the high protein content (20.59%). In second year (2024), sunflower showed a remarkable increase in green mass (52,653 kg/ha) and available nitrogen (207.41 kg/ha) (Figure 1 and 2).

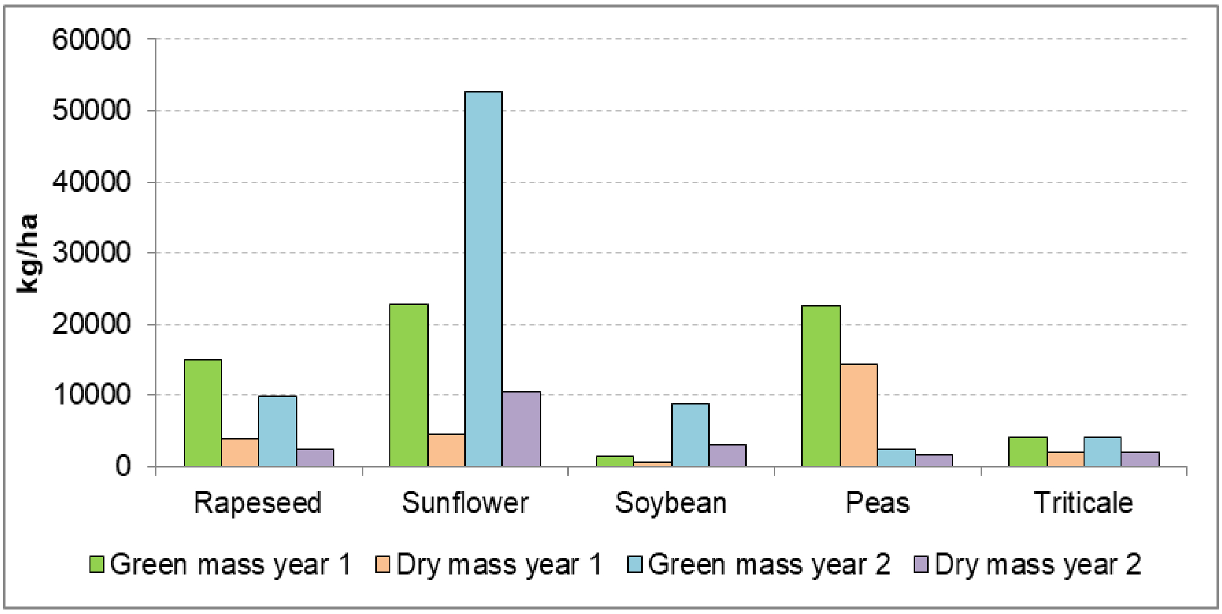

Figure 1. Green mass and dry mass content according to the experimental year by species

For the estimation of nitrogen content we used the Kjeldahl method. This method is used for the quantitative estimation of nitrogen, which is contained in organic, and as well as inorganic compound ammonia (NH_3), or ammonia substances (NH_4^+) (Goyal et al., 2022).

Nitrogen is a quantitative and qualitative determinant in crops (Rusu et al., 2024). Although soybean had the highest percentage of protein (21.55%), the total amount of nitrogen available was limited by the reduced green mass (Figure 2).

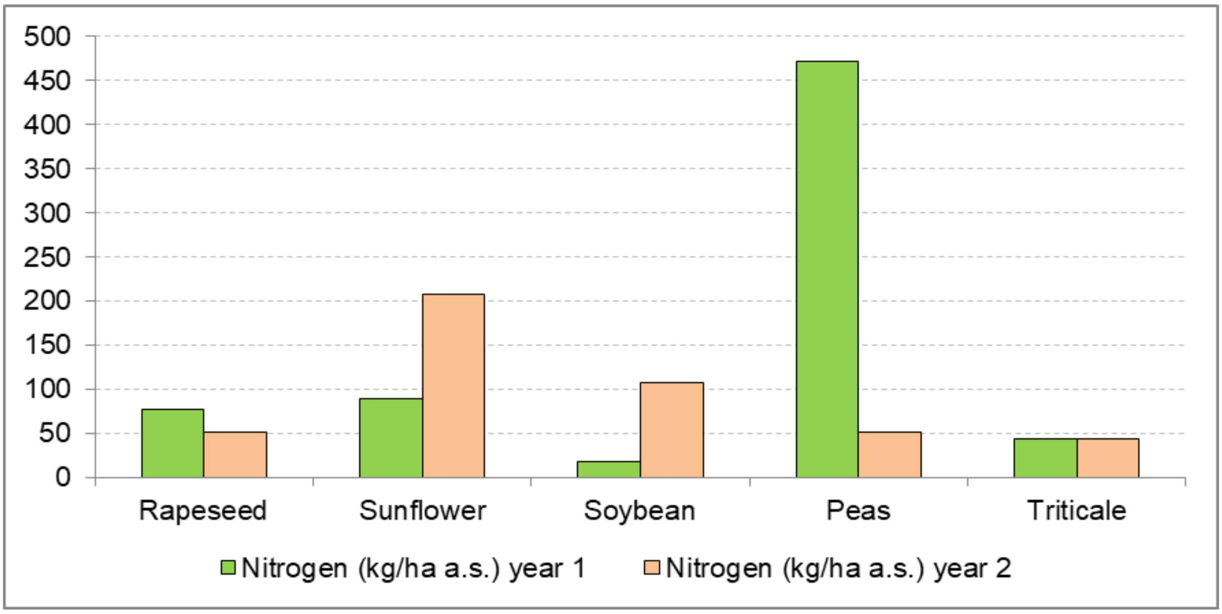

Figure 2. Nitrogen content according to the green manure species related to the year

Increasing or decreasing pH significantly influence the nutrients in soil and ultimately affect the growth andyield of plants (Penn and Camberato, 2019; Gondal et al., 2021).

Changing the pH of the soil has a direct impact on the essential nutrients and, as a result, the growth and yield of crops (Pietri and Brookes, 2008; Shi et al., 2009; Husnain et al., 2021).

The evolution of soil pH according to the main crops (wheat, sunflower and maize), the use of green manures (A) and the application of chemical fertilization (B) are shown in the figure below (Figure 3). It is observed that chemical fertilization (B1) generally maintains a higher pH compared to the unfertilized variant (B2). Green manures have had varied effects. Rapeseed, in combination with chemical fertilization (A2+B1), keeps the pH stable in wheat and sunflower crops, and in the unfertilized version (A2+B2), the soil pH increases significantly in sunflower, reaching 6.46 in the second year. Sunflower (A3) as a green manure contributes to the stability of soil pH, especially under fertilization conditions (B1). Conversely, peas (A5) and triticale (A6) tend to contribute to soil acidification, especially in the unfertilized variant (B2), indicating a negative influence on pH values, especially in the first year.

Across crops, wheat shows a decrease in pH throughout the experiment, while sunflowers benefit from the largest positive variations. Maize has relatively constant values, with slight increases in the fertilized variants.

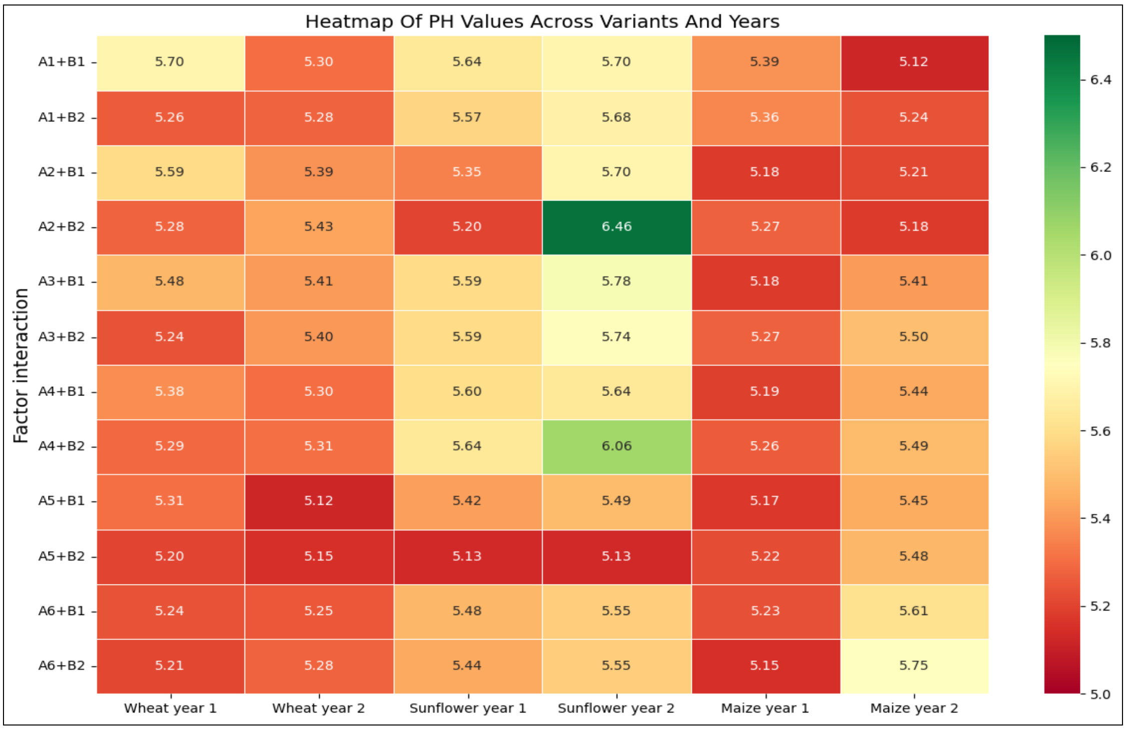

Figure 3. Changes in pH by species and years

The graph highlights the influence of green manures on soil pH in two consecutive years regardless of chemical fertilization (Figure 4). Rapeseed and soybean maintain higher soil pH in the second year (5.69 and 5.62), but in each variant an increase is observed, suggesting a beneficial effect on acidity. In contrast, the control shows no changes in pH, again emphasizing the importance of green manures in reducing soil acidity.

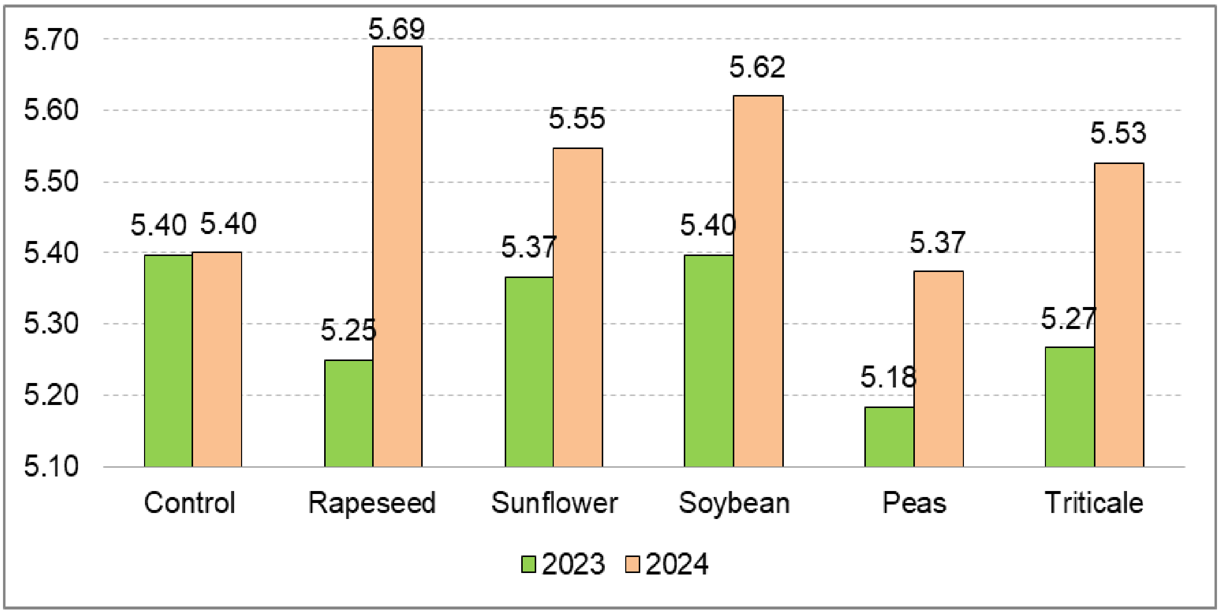

Figure 4. Influence of green manures on pH

Regarding the influence of chemical fertilization on soil pH in two consecutive years, it is observed that in the chemical fertilized version, the pH is slightly higher, with a notable increase in the second year. In contrast, in the unfertilized variant, the pH remains very low in the first year and increases significantly in the second year, suggesting a natural improvement or a delayed effect of previous fertilization (Figure 5).

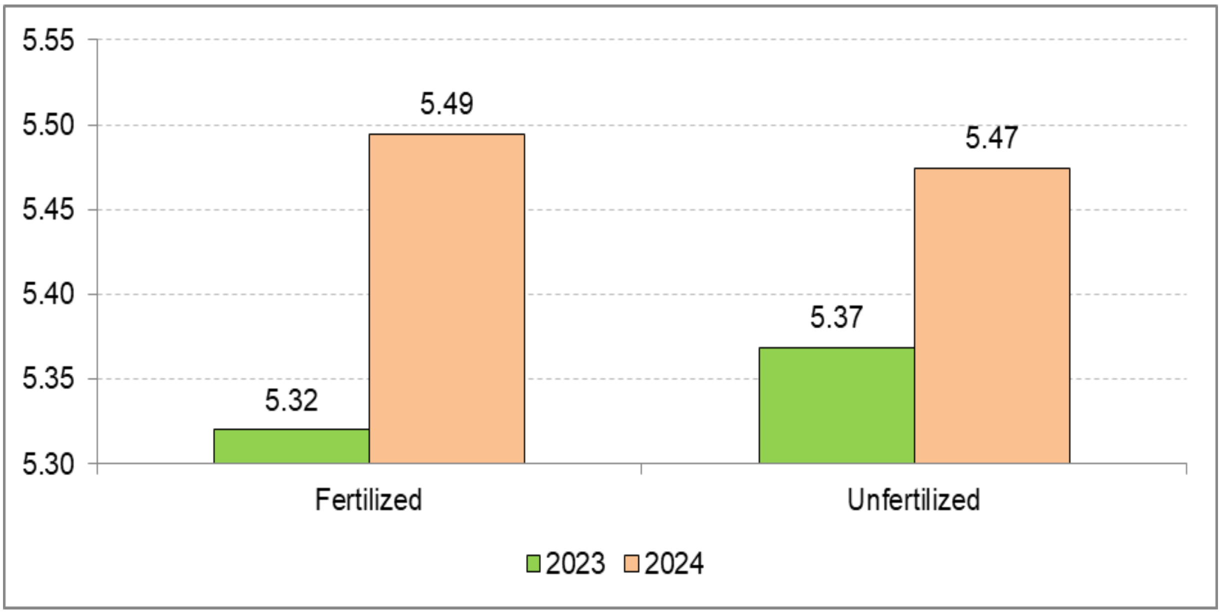

Figure 5. Influence of chemical fertilization on pH

A study demonstrates that green manure incorporation increased the soil moisture, total nitrogen, total phosphorus, basal respiration, soil organic carbon and its labile fractions, and enzyme activities (Tovar Hernandez et al., 2023). The tables show the variations in the content of total nitrogen (N_t), corrected organic carbon (C_{org}) and humus in the soil according to the use of green manures and chemical fertilization (F) or in its absence (N). In 2023, after green manures, chemical fertilization helped increase soil fertility. For example, Control F recorded higher values of N_t (0.163%) and humus (1.66%). Green fertilizers such as fertilized soybeans (F) had a positive impact, with high values of N_t (0.150%) and humus (1.59%). Conversely, unfertilized triticale (N) had the lowest content of N_t (0.106%) and humus (1.55 %), which suggests a lower efficiency in soil improvement (Table 2). Soil organic carbon and its labile fractions, and total nitrogen were observed as the main drivers of the maize production (Tovar Hernandez et al., 2023) Carbon management is necessary for a complexity of matters including soil, water management, field productivity, biological fuel and climatic change (Wang et al., 2025).

Table 2. Evolution of total nitrogen, organic carbon and humus in first year of experimentation (2023)

No. crt.	Identification	Tests performed Year 1 after green manures		
		N_t	C_{org}	Humus
		%	%	%
1	Control F	0.163	0.96	1.66
2	Control N	0.132	1.03	1.77
3	Rapeseed F	0.138	0.90	1.55
4	Rapeseed N	0.116	0.90	1.55
5	Sunflower F	0.135	0.96	1.66
6	Sunflower N	0.113	0.99	1.71
7	Soya F	0.150	0.92	1.59
8	Soya N	0.121	0.93	1.60
9	Peas F	0.121	0.93	1.60
10	Peas N	0.110	0.95	1.65
11	Triticale F	0.128	0.93	1.60
12	Triticale N	0.106	0.90	1.55

In 2024, after green manures, Sunflower F demonstrated the highest efficiency, with values of N_t (0.153%) and humus (1.70%). In contrast, the control variants N recorded a significant reduction of N_t (0.065%), indicating a possible depletion of soil nitrogen. Also, unfertilized Triticale (N) showed low values of N_t (0.054%) and humus (1.58%), suggesting a limited contribution to soil fertility (Table 3).

Table 3. Evolution of total nitrogen, organic carbon and humus in second year of experimentation (2024)

No. crt.	Identification	Tests performed Year 2 after green manures		
		N_t	C_{org}	Humus
		%	%	%
1	Control F	0.150	0.94	1.62
2	Control N	0.065	0.95	1.64
3	Rapeseed F	0.146	0.90	1.56
4	Rapeseed N	0.107	0.89	1.54
5	Sunflower F	0.153	0.99	1.70
6	Sunflower N	0.147	0.84	1.44
7	Soya F	0.131	0.95	1.64
8	Soya N	0.129	0.97	1.67
9	Peas F	0.143	1.03	1.78
10	Peas N	0.124	1.02	1.76
11	Triticale F	0.120	0.95	1.64
12	Triticale N	0.054	0.92	1.58

The analyzed data show a polynomial correlation between total nitrogen (N_t) and soil pH, with a coefficient of determination (R^2=0.422), indicating a moderate relationship. As nitrogen content increases, pH tends to increase, reflecting an improvement in soil acidity at higher nitrogen levels (Figure 6).

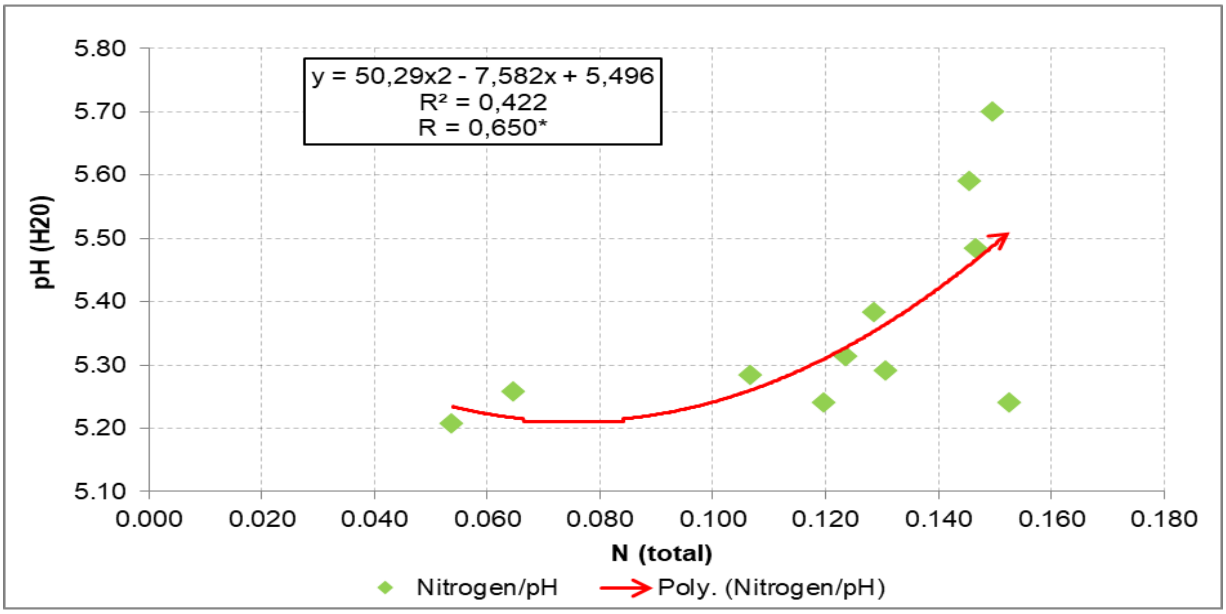

Figure 6. Polynomial interaction between total nitrogen and pH

The data was analyzed statistically using the ANOVA method (Liu and Wang, 2021; Okoye and Hosseini, 2024).The combination of chemical fertilizer and green manure can effectively enhance the distribution ratio of N from both sources in wheat grains (Mao et al., 2024).

Both the individual influences of experimental factors A, and B on production, as well as the interactions between these factors, were analyzed, providing a complete picture of how each factor contributes to the final result.

Compared to the chemically non-fertilized control, the significant inferiority of the rapeseed variant without chemical fertilizer and distinctly significant of the sunflower variant without chemical fertilizer can be noted. Through chemical fertilization, all variants brought very significant increases compared to the non-chemically fertilized control (Table 4).

Table 4. Interaction of factors on the average production of wheat in the years 2023-2024

No. crt.	Variant	Average production 2023-2024 (kg/ha)	Difference± compared from fertilized control	Difference± from unfertilized control	Significance relative to fertilized control	Significance relative to unfertilized control
1	Control F	7064	-	3344		***
2	Control N	3720	-3344	-	000	
3	Rapeseed F	6822	-242	3102		***
4	Rapeseed N	3302	-3762	-418	000	
5	Sunflower F	6860	-204	3140		***
6	Sunflower N	3175	-3889	545	000	
7	Soybean F	7164	1	3444		***
8	Soybean N	3664	-340	-56	000	
9	Peas F	6827	-237	3107	-	***
10	Peas N	3894	-317	174	000	
11	Triticale F	7241	177	3521		***
12	Triticale N	3684	338	36	000	

*** indicate significant positive differences for probability P<0.001 and 000 indicate significant negative differences for probability P<0.001.

The F-test based on the comparison of the calculated F-value with the theoretical F-value results in statistical assurance for 5%, 1% and 0.1%. By calculating the limit differences (DL), the variants proved to have different statistical significances, resulting compared to the chemically fertilized control, the highly significant inferiority of all variants of green manure without chemical fertilization and yield differences statistically reassured by chemical fertilization (Table 4). The yield difference of the averages of the two years compared to the average of the experience shows very significant increases by chemical fertilization and very significant decreases by non-chemical fertilization in interaction with any of the green manures (Table 5).

Table 5. Interaction of factors on average wheat production in the years 2023-2024

No. crt.	Variant	Average production 2023-2024 (kg/ha)	Difference± from average	Significance
1	Control F	7064	1780	***
2	Control N	3720	-1564	000
3	Rapeseed F	6822	1538	***
4	Rapeseed N	3302	-1982	000
5	Sunflower F	6860	1576	***
6	Sunflower N	3175	-2109	000
7	Soybean F	7164	1980	***
8	Soybean N	3664	-1620	000
9	Peas F	6827	1543	***
10	Peas N	3894	-1390	000
11	Triticale F	7241	1957	***
12	Triticale N	3684	-1600	000
13	**Average (Ct.)**	**5284**		

*** indicate significant positive differences for probability P<0.001and 000 indicate significant negative differences for P<0.001.

The creation of an optimal level of mineral nutrition of plants is important in the system of agricultural activities aimed at increasing the yield of sunflower (Vinogradov et al., 2021).

The table highlights the influence of green fertilizers on sunflower production in 2023. The control (A1) recorded a production of 2051 kg/ha. The use of rapeseed (A2) and sunflower (A3) as green manures generated significant increases in production, reaching 2681 kg/ha and 2685 kg/ha, respectively, with positive differences of 630 kg/ha and 634 kg/ha from as a Control.

The best results were obtained with soybean (A4) (3060 kg/ha) and pea (A5) (3194 kg/ha), which showed distinctly significant differences, with increases of 1009 kg/ha and 1143 kg, respectively, /ha versus the Control (Table 6).

Table 6. Influence of factor A on sunflower production in 2023

Factor A	Production (kg/ha)	Difference± from control	Significance
Control	2051	Ct.	Ct.
Rapeseed	2681	630	*
Sunflower	2685	634	*
Soybean	3060	1009	**
Peas	3194	1143	**
Triticale	2447	396	

* and ** indicate P<0.05 and P<0.01, respectively.

The table shows the interaction between factors A - green manure and B - chemical fertilization on sunflower production. In the fertilized variant (B1), the highest productions were recorded for peas (A5) (3524 kg/ha), soybeans (A4) (3440 kg/ha) and sunflowers (A3) (3399 kg/ha), with significant increases compared to the control. Rapeseed (2910 kg/ha) and triticale (2690 kg/ha) recorded lower increases, and the differences were not significant.

In the variants without chemical fertilizer (B2), yields were lower, but peas (2863 kg/ha) and soybeans (2679 kg/ha) recorded distinctly significant differences compared to the control.

The results show that peas and soybeans are the most effective green manures, especially in combination with chemical fertilization. Chemical fertilization had a clear impact on production increases in all variants (Table 7).

Table 7. The interaction of factors A+B on sunflower production in the year 2023

Factor A + Factor B1	**Production (kg/ha)**	**± difference from control**	**Significance**
Control F	2542	Ct.	Ct.
Rapeseed F	2910	368	
Sunflower F	3399	857	*
Soy F	3440	898	*
Peas F	3524	982	*
Triticale F	2690	148	-
Factor A + Factor B2	**Production (kg/ha)**	**± difference from control**	**Significance**
Control N	1559	Ct.	Ct.
Rapeseed N	2452	892	*
Sunflower N	1970	411	
Soy N	2679	1119	**
Peas N	2863	1303	**
Triticale N	2203	643	

* and ** indicate P<0.05 and P<0.01, respectively.

The table shows the production of sunflowers in the year 2024, in climatic conditions specific to that year. The control had a production of 1813 kg/ha, being used as a reference. The lowest production was recorded for the rapeseed variant (A4) which registered an increase of 232 kg/ha, with a positive significance. The variant with peas had the highest production, with 2741 kg/ha, generating a very significant positive increase (929 kg/ha). Also, the rest of the variants with green fertilizers generated very significantly positive sunflower differences (Table 8).

Table 8. Influence of factor A on sunflower production in 2024

Factor A	**Production (kg/ha)**	**Difference± from control**	**Significance**
Control	1813	0	Ct.
Rapeseed	2045	232	*
Sunflower	2447	634	***
Soybean	2393	581	***
Peas	2741	929	***
Triticale	2533	720	***

* and *** indicate $P<0.05$ and $P<0.001$, respectively.

In the fertilized variants (B1), the control recorded a production of 2006 kg/ha. The highest yields were observed in the triticale variant (774 kg/ha), followed by sunflower (768 kg/ha), peas (756 kg/ha) and soybeans (655 kg/ha). These variants demonstrate the effectiveness of green manures combined with chemical fertilization in increasing production.

In the non-fertilized variants (B2), the control had a production of 1619 kg/ha, and the pea obtained the highest increase of 1101 kg/ha, reaching 2720 kg/ha. Triticale also recorded a highly significant positive gain of 667 kg/ha, while sunflower and soybean had distinctly significant gains of 500 kg/ha and 506 kg/ha. Canola achieved a smaller but significant difference of 315 kg/ha (Table 9).

Table 9. The interaction of factors A+B on sunflower production in 2024

Factor A + Factor B1	**Production (kg/ha)**	**Difference ±from control**	**Significance**
Control F	2006	0	Ct.
Rapeseed F	2155	149	-
Sunflower F	2774	768	***
Soy F	2661	655	***
Peas F	2762	756	***
Triticale F	2780	774	***
Factor A + Factor B2	**Production (kg/ha)**	**Difference ±from control**	**Significance**
Control N	1619	0	Ct.
Rapeseed N	1934	315	*
Sunflower N	2119	500	**
Soy N	2125	506	**
Peas N	2720	1101	***
Triticale N	2286	667	***

*, **and *** indicate $P<0.05$, 0.01 and $P<0.001$, respectively.

In the year 2023, we obtained a production of 7208 kg/ha in the maize culture in the control version without green manure. The highest maize production was recorded in the pea variant with a very significantly positive difference of 1009 kg/ha compared to the control. The rest of the variants brought distinctly significantly positive increases in production, less the triticale variant, in which case a production of 6741 kg/ha was obtained, with a significant negative difference of -467 kg/ha compared to the control. The results show that pea is the most effective green manure for maize production (Table 10).

Table 10. Influence of factor A on maize production in 2023

Factor A	Production (kg/ha)	Difference ±from control	Significance
Control	7208	0	Ct.
Rapeseed	7838	630	**
Sunflower	7788	580	**
Soybean	7824	616	**
Peas	8217	1009	***
Triticale	6741	-467	0

and * indicate $P<0.01$ and $P<0.001$, respectively, and 0 indicate significant negative differences for $P<0.05$.

In the chemically fertilized variants (B1), the control recorded a production of 9625 kg/ha as well as the variant with triticale F. The rest of the variants showed significant and distinctly significant negative differences. The lowest production was obtained for the F pea variant of 8357 kg/ha, with a difference of over 1.2 t/ha compared to the control.

In the non-fertilized variants (B2), peas had the highest production (8077 kg/ha), with a very significant increase of 3288 kg/ha, followed by soybean (2072 kg/ha) and rapeseed (1588 kg/ha). There is no significance in the sunflower green fertilizer variant, the difference being 471 kg/ha, and in the triticale variant there is a significant negative difference (Table 11).

Table 11. The interaction of factors A+B on maize production in 2023

Factor A + Factor B1	Production (kg/ha)	Difference ±from control	Significance
Control F	9625	0	Ct.
Rapeseed F	9298	-327	-
Sunflower F	8714	-911	0
Soy F	8786	-839	0
Peas F	8357	-1268	00
Triticale F	9625	0	-
Factor A + Factor B2	**Production (kg/ha)**	**Difference ±from control**	**Significance**
Control N	4791	0	Ct.
Rapeseed N	6379	1588	***
Sunflower N	5262	471	-
Soy N	6863	2072	***
Peas N	8077	3286	***
Triticale N	3857	-934	0

*** indicate significant positive differences for probability $P<0.001$ and 000 indicate significant negative differences for $P<0.05<0.01$.
DL (p 5%) 668.23 kg/ha
DL (p 1%) 941.61 kg/ha
DL (p 0.1%) 1339.79 kg/ha

In 2024, the maize crop suffered due to harsh climatic conditions from an agronomic point of view, in the Livada area and north-west Romania. Due to long periods of drought, maize production has decreased by almost 30% and in a few cases even halved.

In 2024, the control achieved a production of 3290 kg/ha, peas had the highest production increase (1083 kg/ha) and a statistical significance. The sunflower and rapeseed variants had moderate increases (675 kg/ha and 179 kg/ha), but not statistically significant. The triticale variant obtained the highest increase (3532 kg/ha) compared to the control with a very significant positive difference.

Table 12. Influence of factor A on maize production in 2024

Factor A	Production (kg/ha)	Difference ±from control	Significance
Control	3290	0	Ct.
Rapeseed	3468	179	
Sunflower	3964	675	
Soybean	4794	1504	**
Peas	4373	1083	*
Triticale	6821	3532	***

*, **and *** indicate P<0.05, 0.01 and P<0.001, respectively.

In the fertilized variants, the triticale variant had the highest production (7111 kg/ha), with a very significant increase of 667 kg/ha. Soybean (5238 kg/ha) generated a distinctly significant increase, and peas, sunflowers and rape had smaller, insignificant differences. In the non-fertilized variants, again the triticale (6532 kg/ha) had the highest, highly significant gains compared to the control. The results highlight that the climatic conditions of the year 2024 triticale fertilizer offers the greatest increases in production, regardless of chemical fertilization (Table 13).

Table 13. The interaction of factors A+B on maize production in 2024

Factor A + Factor B1	Production (kg/ha)	Difference ±from control	Significance
Control F	3698	0	Ct.
Rapeseed F	3936	238	
Sunflower F	3762	63	
Soy F	5238	1540	**
Peas F	4365	667	
Triticale F	7111	3413	***
Factor A + Factor B2	**Production (kg/ha)**	**Difference ±from control**	**Significance**
Control N	2881	0	Ct.
Rapeseed N	3000	119	
Sunflower N	4167	1286	*
Soy N	4349	1468	*
Peas N	4381	1500	**
Triticale N	6532	3651	***

*, **and *** indicate P<0.05, 0.01 and P<0.001, respectively.

CONCLUSIONS

In this study, the effects of green manures and chemical fertilizers on acid soils in northwestern Romania were investigated, using three main crops (wheat, sunflower and maize). The main objective was to reduce acidity, increase soil fertility and optimize agricultural productivity by integrating sustainable methods.

The argiloiluvial soil characteristic of the study area has a high acidity and a defective hydro-aerial regime. The applied method had a positive impact, increasing the amount of humus and improving the C:N ratio.

All three crops responded positively to the combination of green and chemical fertilizers, demonstrating increased productivity compared to conventional fertilization methods.

Wheat was the crop most positively influenced by the application of the green manures and chemical fertilizers. The average yield of wheat increased by 18% in plots with green and chemical fertilizers compared to controls. The final production was 6.2 t/ha, in contrast to 5.1 t/ha in the case of the control variants.

The sunflower also benefited from the applied method. Sunflower recorded a 15% increase in yield in the variants with applied fertilizers, reaching an average production of 3.8 t/ha, compared to 3.3 t/ha in the control variants.

Maize production in 2023 increased by 31%, reaching an average production of 7179 kg/ha, compared to 5464 kg/ha in the control variant. In the year 2024, the maize crop suffered due to weather conditions in which it was shown that in the non-chemically fertilized variants, each variant with green manure achieved a production increase compared to the control without green manure.

The obtained results confirm that the combined approach of green and chemical fertilizers is a viable solution for sustainable agriculture. This method allows an efficient management of soil resources, contributing to the protection of biodiversity and the sustainable growth of agricultural production.

REFERENCES

Davidescu, D., and Davidescu, V., 1981. *Modern Agrochemistry*. Publishing House of the Academy of the Socialist Republic of Romania, Bucharest.

Dumitru, M., Šimota, C., Doreanu, E, Geambașu, N., Stanciu, P., Țigănaș, L., Iliescu, H., Țogoe, I., Munteanu, I., Dumitru, E., Mitroi, A., 2003. *Code of Good Agricultural Practices*. Expert Publishing House, vol. 1, Bucharest.

Eliade, G., Ghinea, L., Stefanic, G., 1975. *Soil microbiology. The biological bases of agrotechnic*s. CERES Publishing House, Bucharest.

Florea, N., and Munteanu, I., 2012. *Romanian Soil Taxonomy System (SRTS*). Sitech Publishing House, Craiova.

Gondal, A.H., Hussain, I., Ijaz, A.B., Zafar, A., Ch., B.I., Zafar, H., Sohail, M.D., Niazi, H., Touseef, M., Ali Khan, A., Tariq, M.., Yousuf, H., Usuma, M., 2021. *Influence of soil pH and microbes on mineral solubility and plant nutrition: A review*. International Journal of Agriculture and Biological Sciences, 5(1): 71-81.

Goyal, K., Singh, N., Jindal, S., Kaur, R., Goyal, A., Awasthi, R., 2022. *Kjeldahl method*. Advanced Techniques of Analytical Chemistry, 1(1), 105.

Husnain, A., Farooq, Q., Sohail, S., Shasang, S., Toor, D., Zafar, A., Rehman, B., 2021. *Adaptability of soil pH through innovative microbial approach*. Current Research in Agricultural Sciences, 8(2): 71-79.

Ionescu, A., Sion, I., Stanciu, M., 1978. *Protection of ecosystems*. Publishing House National Commission of RS Romania for UNESCO, Bucharest.

IUSS Working Group WRB, 2015.*World Reference Base for Soil Resources 2014, Update 2015. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps*. FAO, Rome. http://www.fao.org/3/i3794en/I3794en.pdf

Liu, Q., and Wang, L., 2021. *t-Test and ANOVA for data with ceiling and/or floor effects*. Behavior Research Methods, 53(1): 264-277.

Manea, D., Dumitru, M., Florea, N., Răcășan, C., 2009. *Morphological, physico-chemical and pedogenetic characterization of soils from the Ampoi Basin, Alba County*. Agronomic Research in Moldova, 4(2): 25-37.

Mao, X., Li, Z., Yan, Q., Xu, K., Han, M., 2024. *Nitrogen Fate of Chemical Fertilizer and Green Manure-Wheat Rotation Using 15 N Tracer Technique*. Romanian Agricultural Research, 41: 141-152. https://doi.org/10.59665/rar4114

Martínez-Dalmau, J., Berbel, J., Ordóñez-Fernández, R., 2021. *Nitrogen fertilization. A review of the risks associated with the inefficiency of its use and policy responses*. Sustainability, 13(10), 5625.

Naie, M., Mîrzan, O., Bărcan, D.M., Stavarache, M., Dumitriu, S., Stavarache, E., Muscalu, A., Rusu, D.B., Lungoci, C., 2024. *Productivity and Vegetation Structure Evolution of Complex Mixtures of Perennial Forage Grasses and Leguminous Species, in the Conditions of the Center of Moldova, Romania*. Romanian Agricultural Research, 41: 241-252. https://doi.org/10.59665/rar4122

Okoye, K., and Hosseini, S., 2024. *Analysis of variance (ANOVA) in R: One-way and two-way ANOVA*. R Programming: Statistical Data Analysis in Research, Singapore, Springer Nature Singapore: 187-209. https://link.springer.com/chapter/10.1007/978-981-97-3385-9_9

Penn, C.J., and Camberato, J.J., 2019. *A Critical Review on Soil Chemical Processes that Control*

How Soil pH Affects Phosphorus Availability to Plants. Agriculture, 9(6), 120.

Pietri, J.A., and Brookes, P.C., 2008.*Relationships between soil pH and microbial properties in a UK arable soil*. Soil Biology and Biochemistry, 40(7): 1856-1861.

Ren, K., Xu, M., Li, R., Zheng, L., Liu, S., Reis, S., Wang, H., Lu, C., Zhang, W., Gao, H., Duan, Y., Gu, B., 2022. *Optimizing nitrogen fertilizer use for more grain and less pollution*. Journal of Cleaner Production, 360, 132180.

Rusu, M., Mihai, M., Tritean, N., Mihai, V., Moldovan, L., Ceclan, O.A., Russu, F., Toader, C., 2024. *Results of Long Term Fertiliser Experiments-Use in Sustainable Soil Fertility Protection Measures*. Romanian Agricultural Research, 41: 329-341. https://doi.org/10.59665/rar4131

Shi, W., Liu, J., Du, Z., Song, Y., Chen, C., Yue, T., 2009. *Surface modelling of soil pH*. Geoderma, 150(1-2): 113-119.

Sîrca, C., 1997. *Research on the culture of lupine (Lupinus albus) on brown loess soils in the northwest of the country*. PhD thesis, ASAS, Bucharest.

Șerban, D., 2014. *Soil. Soil types and general characteristics*. Ceres Publishing House, Bucharest.

Șerdinescu, A., Ion, M., Fîciu, L., Brînduşe, E., 2023. *The Impact of Conservative Soil Maintenance Practices in Vineyards on Soil Microbial Diversity and on the Biodiversity of Useful and Harmful Entomofauna*. Romanian Agricultural Research, 40: 327-334. https://doi.org/10.59665/rar4031

Ștefan, V., 2000. *Ecopedology*. Marineasa Publishing House, Timişoara.

Takil, E., and Kayan, N., 2023. *Nitrogen inhibators and rhizobia can improve yield and yield components in bean*. Romanian Agricultural Research, 40: 131-138. https://doi.org/10.59665/rar4012

Tovar Hernandez, S., Carciochi, W.D., Diovisalvi, N.V., Izquierdo, N., Wyngaard, N., Barbieri, P., Calvo, N.I.R., 2023. *Does nitrogen fertilization rate, timing, and splitting affect sunflower yield and grain quality?* Crop Science, 63(3): 1525-1540.

Vinogradov, D.V., Makarova, M.P., Kryuchkov, M.M., 2021. *The use of mineral fertilizers in sunflower crops in the conditions of Ryazan region*. IOP Conference Series: Earth and Environmental Science, IOP Publishing, 624, 1, 012077.

Vista, S.P., Gaihre, Y.K., Dahal, K.R., 2024. *Plant nutrient availability in acid soil and management strategies*. Climate Change and Soil-Water-Plant Nexus: Agriculture and Environment, Singapore, Springer Nature Singapore: 331-353.

Wang, G., Li, H., Hu, F., Yin, W., Fan, Z., Fan, H., Sun Y., He, W., Chai, Q., 2025. *Application of green manure combined with synthetic nitrogen fertilizer enhances soil aggregate stability in an arid wheat cropping system*. Applied Soil Ecology, 206, 105849.

Zaldea, G., Alexandru, L.C., Nechita, A., Filimon, R., Damian, D., 2023. *Evolution of the precipitation regimen and humidity reserves in the soil of vineyards in the north-eastern part of Romania*. Acta Agricola Romanica, 5, 5(2): 106-113.

Zhang, Y., Ye, C., Su, Y., Peng, W., Lu, R., Liu, Y., Huang, H., He, X., Yang, M., Zhu, S., 2022. *Soil Acidification caused by excessive application of nitrogen fertilizer aggravates soil-borne diseases: Evidence from literature review and field trials*. Agriculture, Ecosystems and Environment, 340, 108176.