CROP RESPONSE TO GREEN MANURE SYSTEMS IN ACIDIC ALBIC LUVISOLS

Ács Peter Balázs[1] *– Mondici Susana*[1] *– Ursan Patrick-Andrei*[1] *– Andraş Beniamin-Emanuel*[1] *– Jurje Mara-Oana*[1] *– Smit Gergely-Andrei*[1]

[1]Agricultural Research and Development Station Livada (ARDS Livada), 7 Baia Mare Street, 447180 Livada, Satu Mare County, Romania

Introduction

The combined use of chemical and organic fertilizers is a promising approach for rapidly correcting nutrient deficiencies and improving soil structure, particularly in agricultural systems facing the dual pressures of maintaining productivity while preserving long-term soil health. Chemical fertilizers provide immediate nutrient availability, allowing crops to overcome acute deficiencies within a short timeframe, whereas organic amendments contribute to the gradual build-up of soil organic matter, improved water retention, and enhanced biological activity. Adapting and applying this integrated approach to the specific needs of the soil and crops enhances the benefits of both fertilizer types, minimizes their respective drawbacks, and contributes to the sustainable increase in agricultural production over successive growing seasons.

Within this framework, the use of green manures and cover crops has emerged as a particularly valuable practice, offering multiple agronomic and environmental benefits. These include reducing soil water evaporation, preventing erosion on exposed or sloped land, maintaining more stable and optimal soil temperatures, and improving soil structure through increased aggregation and porosity. When incorporated into the soil, green manures decompose and release essential nutrients, such as nitrogen, phosphorus, and potassium, back into the soil profile, making them available to subsequent crops and reducing reliance on external fertilizer inputs.

Given these documented benefits, the primary objective of this research is to assess the effects of green manures and their combinations with chemical fertilizers on soil fertility and the performance of major agricultural crops, namely wheat, maize, and sunflower. By examining both the standalone and combined effects of these amendments, the study aims to provide a clearer understanding of how green manure practices can be optimized within conventional fertilization systems.

Keywords: green manure crops; soil fertility; crop yield; nitrogen dynamics; sustainable cropping systems

Literature review

Soil fertility management is one of the most important factors affecting agricultural production. The use of organic fertilizers, including green manure, is an important strategy for maintaining or improving soil fertility for sustainable agricultural production (Aka Sagliker and Kizildag Ozdal, 2021; Kosztyuné Krajnyák et al., 2024; Csabai et al., 2022; Csabai et al., 2021; Takin et al., 2023; Shiferaw et al., 2011).

In general, green manure refers to crops that provide fertilizer for major agricultural crops and improve soil productivity. The use of green manure is a traditional and valuable practice for managing agroecosystems (Tovar et al., 2023).

Both chemical fertilizers and green manure can increase the efficiency of nitrogen use. Lei and colleagues (2022) showed that replacing chemical fertilizers with green manure can improve the growth environment for rice roots and increase root density, biomass, activity, and nutrient uptake (Wang et al., 2025). In addition, legumes used as green manure can provide extra nitrogen to the soil (Crews et al., 2004; Drinkwater et al., 1995; Györgyiné Kovács et al., 2025).

The application of green manure provided a more stable nitrogen supply and reduced the potential for nitrification by decreasing nitrification substrates, thereby maintaining a relatively stable trend in soil NH_4^+-N. This, in turn, reduced soil nitrogen volatilization, leaching, and runoff, helping protect the aquatic and atmospheric environments. (Rudisil et al., 2016)

Furthermore, the incorporation of green manure results in a rapid increase in the number of soil microorganisms; however, the high C/N and C/P ratios of non-leguminous green manure crops increase microorganisms' uptake of available N and P, thereby reducing the initial levels of available N and P in the soil during the early stage of green manure incorporation and subsequently inhibiting the early growth of rice

Green manure contains major macronutrients (N, P, K) and several micronutrients (Ca, Mg, Si), which not only transfer nutrients to the soil and ensure a balanced and sustainable supply of nutrients in paddy fields but also promote the uptake of nutrients from deeper soil layers by rice roots (Lei et al., 2022).

The method of using green manure varies depending on the climate, soil, the type of plant used as green manure, and the agronomic characteristics of the first crop being fertilized (Naz et al., 2023). With regard to climate, the application of green manure is recommended primarily for humid areas and secondarily for intermediate areas. As for soil, green manure can be applied to any type of soil, but it is of greater importance for podzolic and sandy soils (Naie et al., 2024). In these areas, insufficient forage resources make conditions unfavorable for raising livestock and, consequently, for supplying the farm with manure. On such soils, due to unsuitable physical conditions and poor nutrient and water supply, other measures aimed at restoring soil fertility also fail to yield satisfactory results (Sigfried, 2012).

Green manure is a viable and sustainable way to improve the fertility of acidic soils. Integrating it into agricultural practices can significantly help restore and maintain soil health. However, it is essential to evaluate and adapt these methods to the specific characteristics of each plot of land and the needs of the crops being grown (Păcurar et al., 1999a,b).

Material and method

The experiment was conducted on the experimental fields of the Agricultural Research and Development Station (ARDS) Livada in Romania and included three main crops: wheat, sunflower, and maize. The same experimental methodology was applied to all three crops, using identical variants. For each crop, the cultivation technology specific to the Livada area and the northwestern region of Romania was followed, adapted to local pedoclimatic conditions and the specific requirements of each crop.

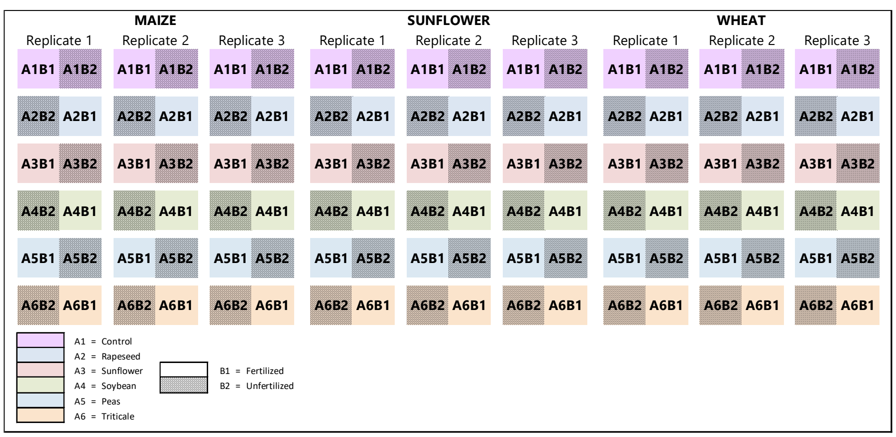


Figure 1. Experimental layout

The experiment was conducted using the split-plot design with three replicates and included three main experimental factors (Figure 1):

Factor A consisted of plant species used as green manures:

- A1 – Control (no green manure)
- A2 – Rapeseed
- A3 – Sunflower
- A4 – Soybean
- A5 – Pea
- A6 – Triticale

These species were sown in June, immediately after harvesting the preceding crop (in this case, oats), and were incorporated into the soil in their green state during autumn, approximately at the flowering phenological stage.

Factor B was represented by the chemical fertilizer Calcium ammonium nitrate (NH_4NO_3 + $CaMg(CO_3)_2$), applied at a rate of 450 kg/ha, with two levels:

- B1 – Chemically fertilized
- B2 – Not chemically fertilized

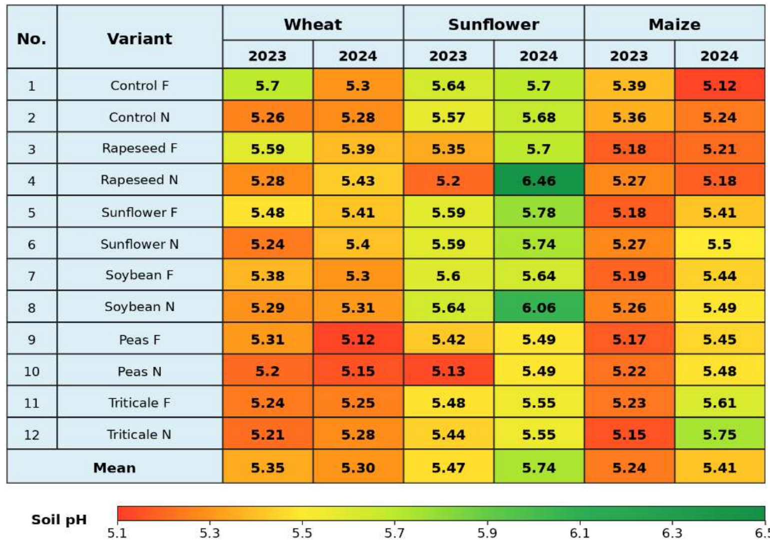
Results and discussion

The results indicate that sunflower produced the highest plant biomass in 2023, reaching 52.6 t/ha. The lowest green biomass was recorded in the soybean variant in 2022, at only 0.5 t/ha. In 2023, the pea green manure variant registered the lowest biomass production, at 2.5 t/ha, due to unfavorable climatic conditions.

Nitrogen content in plant species was determined using the Kjeldahl method (Figure 2). The highest nitrogen accumulation was recorded in the pea crop in 2022, reaching 471.74 kg/ha. This value reflects pea's ability to fix atmospheric nitrogen through symbiosis with nitrogen-fixing bacteria (Rhizobium). Rapeseed and triticale exhibited stable values across the years, with moderate nitrogen accumulation.

Figure 2. Kjeldahl digestion system

Rapeseed as green manure, when combined with chemical fertilization, maintained a stable soil pH in wheat and sunflower crops. In the unfertilized variant, a significant increase in soil pH was observed in sunflower, reaching 6.46 in the second year. In contrast, pea and triticale contributed to soil acidification, particularly in the unfertilized variants, with lower pH levels, especially in the first year (Figure 3).



No.	Variant	Wheat		Sunflower		Maize	
		2023	2024	2023	2024	2023	2024
1	Control F	5.7	5.3	5.64	5.7	5.39	5.12
2	Control N	5.26	5.28	5.57	5.68	5.36	5.24
3	Rapeseed F	5.59	5.39	5.35	5.7	5.18	5.21
4	Rapeseed N	5.28	5.43	5.2	6.46	5.27	5.18
5	Sunflower F	5.48	5.41	5.59	5.78	5.18	5.41
6	Sunflower N	5.24	5.4	5.59	5.74	5.27	5.5
7	Soybean F	5.38	5.3	5.6	5.64	5.19	5.44
8	Soybean N	5.29	5.31	5.64	6.06	5.26	5.49
9	Peas F	5.31	5.12	5.42	5.49	5.17	5.45
10	Peas N	5.2	5.15	5.13	5.49	5.22	5.48
11	Triticale F	5.24	5.25	5.48	5.55	5.23	5.61
12	Triticale N	5.21	5.28	5.44	5.55	5.15	5.75
Mean		5.35	5.30	5.47	5.74	5.24	5.41

Figure 3. Soil pH evolution

The results indicate that green manures, when combined with chemical fertilization, can enhance soil fertility, especially for species like sunflower and soybean. However, efficiency varies by species and treatment.

In 2023, the fertilized control (F) recorded higher values of total nitrogen (N_t, 0.163%) and humus (1.66%) than the unfertilized control (N). Fertilized green manures, such as soybean (F), had a significantly positive impact, with elevated N_t (0.150%) and humus (1.59%). By contrast, unfertilized pea (N) exhibited the lowest N_t (0.110%) and humus (1.54%).

In 2024, the second year after the incorporation of green manures, fertilized sunflower (F) demonstrated the highest efficiency, with N_t of 0.153% and humus of 1.69%, underscoring its beneficial role. In contrast, the fertilized control (F) showed a significant decrease in N_t (0.065%), suggesting possible soil nitrogen depletion. Additionally, fertilized triticale (F) displayed low N_t (0.054%) and humus (1.58%) (Table 1). The relationship between total soil N and soil pH across the treatments is illustrated in Figure 4.

Table 1. Evolution of total nitrogen, organic carbon and humus

No.	Variant	2023			2024		
		N_t	C_{org}	Humus	N_t	C_{org}	Humus
		%	%	%	%	%	%
1	Control N	0.132	1.03	1.77	0.150	0.94	1.62
2	Control F	0.163	0.96	1.66	0.065	0.95	1.64
3	Rapeseed N	0.138	0.90	1.55	0.146	0.90	1.56
4	Rapeseed F	0.116	0.90	1.55	0.107	0.89	1.54
5	Sunflower N	0.113	0.99	1.71	0.147	0.84	1.44
6	Sunflower F	0.135	0.96	1.66	0.153	0.99	1.70
7	Soybean N	0.150	0.92	1.59	0.129	0.97	1.67
8	Soybean F	0.121	0.93	1.60	0.131	0.95	1.64
9	Pea N	0.110	0.95	1.65	0.124	1.02	1.76
10	Pea F	0.121	0.93	1.60	0.143	1.03	1.78

11	Triticale N	0.128	0.93	1.60	0.120	0.95	1.64
12	Triticale F	0.106	0.90	1.55	0.054	0.92	1.58

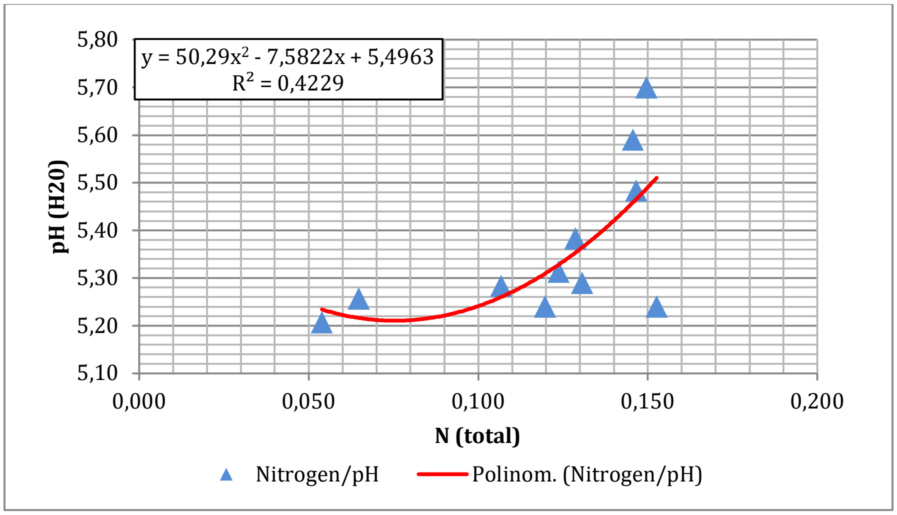


Figure 4. Polynomial interaction of total N and soil pH levels

Influence of Green Manures on the Wheat Crop

Results from 2023 show that, compared with the control, only the green manure variant with pea recorded a significantly higher protein content. The other variants did not show statistically significant differences.

In 2024, the control variant had a protein level of 10.78%, with no significant differences among the experimental treatments. Across the two-year average, no statistically significant differences were observed among the variants. However, considering year interaction effects, the green manure variant with pea showed a significantly higher protein content, reaching 11.09% in the wheat crop (Table 2).

Table 2. The influence of green manures on the protein content of wheat

Variant	**2023**		**2024**		**Mean of years**		**Interaction of year**	
	%	**Dif./signif.**	**%**	**Dif./signif.**	**%**	**Dif./signif.**	**%**	**Dif./signif.**
Control	10.59	Mt.	10.78	Mt.	10.69	Mt.	10.69	Mt.
Rapeseed	10.42	-0.17 ns	10.71	-0.07 ns	10.56	-0.13 ns	10.56	-0.13 ns
Sunflower	10.53	-0.07 ns	10.74	-0.04 ns	10.63	-0.05 ns	10.63	-0.05 ns
Soybean	10.82	0.22 ns	10.78	-0.01 ns	10.80	0.11 ns	10.80	0.11 ns
Pea	11.20	0.61*	10.98	0.20 ns	11.09	0.40 ns	11.09	0.40 *
Triticale	11.07	0.47ns	10.73	-0.05 ns	10.90	0.21 ns	10.90	0.21 ns
	P 5% = 0.55 P 1% = 0.78 P 0.1% = 1.13		P 5% = 0.43 P 1% = 0.60 P 0.1% = 0.88		P 5% = 0.42 P 1% = 0.59 P 0.1% = 0.86		P 5% = 0.33 P 1% = 0.45 P 0.1% = 0.60	

Peas stood out for consistently positive effects, showing significantly higher gluten content in 2023 (17.82% compared to 15.59% in the control) and in the two-year average (17.15% vs. 15.70%). In contrast, rapeseed had a consistently negative impact, with significantly lower gluten values (Table 3) in both years of the study.

Table 3. The influence of green manures on the gluten content

Variant	2023		2024		Mean of years		Interaction of year	
	%	Dif./signif.	%	Dif./signif.	%	Dif./signif.	%	Dif./signif.
Control	15.59	Mt.	15.81	Mt.	15.70	Mt.	15.70	Mt.
Rapeseed	14.72	-0.57^{OO}	15.23	-0.07 ^{ns}	14.98	-0.73 ^{ns}	14.98	-0.73 ^{ns}
Sunflower	15.51	-0.08 ^{ns}	15.73	-0.04 ^{ns}	15.62	-0.08 ^{ns}	15.62	-0.08 ^{ns}
Soybean	16.13	0.03 ^{ns}	15.84	-0.01 ^{ns}	15.98	0.28 ^{ns}	15.98	0.28 ^{ns}
Pea	17.82	0.67**	16.48	0.20 ^{ns}	17.15	1.45**	17.15	1.45**
Triticale	16.03	-0.12 ^{ns}	15.69	-0.05 ^{ns}	15.86	0.16 ^{ns}	15.86	0.16 ^{ns}
	P 5% = 1.94 P 1% = 2.76 P 0.1% = 4.00		P 5% = 0.38 P 1% = 0.54 P 0.1% = 0.79		P 5% = 1.00 P 1% = 1.42 P 0.1% = 2.06		P 5% = 0.92 P 1% = 1.25 P 0.1% = 1.67	

Green manures had limited effects on TKW. None of the green manure crops consistently improved this parameter in a statistically significant way. Soybean and triticale showed negative trends, with lower average values (42.78 g and 42.30 g, respectively) than the control (43.46 g). Statistically significant differences were observed only under certain conditions. Sunflower recorded a slight, non-significant increase (43.68 g) (Table 4).

Table 4. The influence of green manures on the thousand grain weight

Variant	2023		2024		Mean of years		Interaction of year	
	g	Dif./signif.	g	Dif./signif.	g	Dif./signif.	g	Dif./signif.
Control	42.30	Mt.	44.70	Mt.	43.46	Mt.	43.46	Mt.
Rapeseed	41.53	-0.77^{ns}	45.12	0.42^{ns}	43.33	-0.13 ^{ns}	43.45	0.01^{ns}
Sunflower	42.08	-0.22 ^{ns}	45.28	0.58^{ns}	43.68	0.23 ^{ns}	43.73	0.27^{ns}
Soybean	42.63	0.33 ^{ns}	43.77	-0.93^{ns}	42.78	-0.67 ^{O}	42.38	-1.08^{OO}
Pea	42.02	-0.28 ^{ns}	44.60	-0.10^{ns}	43.23	-0.23 ^{ns}	43.31	-0.15^{ns}
Triticale	41.03	-1.27^{O}	43.90	-0.80^{ns}	42.30	-1.16^{OO}	42.47	-0.99 ^{OO}
	P 5% = 1.19 P 1% = 1.69 P 0.1% = 2.45		P 5% = 1.17 P 1% = 1.66 P 0.1% = 2.41		P 5% = 0.60 P 1% = 0.85 P 0.1% = 1.23		P 5% = 0.67 P 1% = 0.90 P 0.1% = 1.21	

Compared to the unfertilized control, the unfertilized rapeseed and sunflower variants showed significantly lower yields. With chemical fertilization, all variants resulted in highly significant yield increases over the unfertilized control. In the first year after the incorporation of green manures, all treatments showed lower yields compared to the control, with statistically highly significant reductions for rapeseed, sunflower, and triticale, and a significant negative result for soybean (-396 kg/ha). Only the pea variant showed a non-significant yield reduction (-115 kg/ha) (Table 5).

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

No.	Variant	Mean yield 2023–2024 (kg/ha)	Difference from fertilized control	Difference from unfertilized control	Significance vs. fertilized control	Significance vs. unfertilized control
1	Control F	7064	-	3344	-	***
2	Control N	3720	-3344	-	OOO	-
3	Rapeseed F	6822	-242	3102	-	***
4	Rapeseed N	3302	-3762	-418	OOO	-
5	Sunflower F	6860	-204	3140	-	***
6	Sunflower N	3175	-3889	545	OOO	-
7	Soybean F	7164	1	3444	-	***
8	Soybean N	3664	-340	-56	OOO	-
9	Pea F	6827	-237	3107	-	***
10	Pea N	3894	-317	174	OOO	-
11	Triticale F	7241	177	3521	-	***
12	Triticale N	3684	338	36	OOO	-
P 5% = 340; P 1% = 455; P 0.1% = 595						

Influence of Green Manures on Sunflower Crop

Triticale and soybean had the most notable effects in 2023, with fat content significantly increasing to 47.40% and 46.77%, respectively, compared with the control (44.38%). Rapeseed maintained fat content above the control in both 2023 (45.72%) and 2024 (44.60%), but these differences were not statistically significant (Table 5).

Table 6. The influence of green manures on the fat content

Variant	2023		2024		Mean of years		Interaction of year	
	%	Dif./signif.	%	Dif./signif.	%	Dif./signif.	%	Dif./signif.
Control	44.38	Mt.	44.18	Mt.	43.28	Mt.	44.28	Mt.
Rapeseed	45.72	1.33^{ns}	44.60	0.42^{ns}	44.93	1.65^{ns}	45.16	0.88^{ns}
Sunflower	46.00	1.62^{ns}	43.80	-0.38^{ns}	44.97	1.68^{ns}	44.90	0.62^{ns}
Soybean	46.77	2.38*	42.42	-1.76^{ns}	44.55	1.27^{ns}	44.59	0.31^{ns}
Pea	44.72	0.33^{ns}	44.08	-0.10^{ns}	45.08	1.80^{ns}	44.40	0.12^{ns}
Triticale	47.40	3.02*	43.67	-0.51^{ns}	44.62	1.33^{ns}	45.53	1.25^{ns}
	P 5% = 2.17 P 1% = 3.09 P 0.1% = 4.48		P 5% = 1.91 P 1% = 2.72 P 0.1% = 3.94		P 5% = 1.96 P 1% = 2.78 P 0.1% = 4.03		P 5% = 1.63 P 1% = 2.21 P 0.1% = 2.95	

Influence on Thousand Kernel Weight

Table 7. The influence of green manures on the thousand kernel weight

Variant	2023		2024		Mean of years		Interaction of year	
	g	Dif./signif.	g	Dif./signif.	g	Dif./signif.	g	Dif./signif.
Control	57.97	Mt.	61.70	Mt.	59.83	Mt.	59.83	Mt.
Rapeseed	56.85	-1.12^{ns}	61.04	-0.66^{ns}	58.94	-0.89^{ns}	58.94	-0.89^{ns}
Sunflower	53.33	-4.63^{OOO}	63.97	2.27**	58.65	-1.18^{ns}	58.65	-1.18^{ns}
Soybean	50.87	-7.10^{OOO}	65.36	3.66***	58.11	-1.72^{O}	58.11	-1.72^{ns}
Pea	56.50	-1.47^{ns}	66.27	4.57***	61.38	1.55*	61.38	1.55^{ns}
Triticale	49.50	-8.47^{OOO}	61.23	-0.46^{ns}	55.37	-4.46^{000}	55.37	-4.47^{OO}
	P 5% = 1.79 P 1% = 2.54 P 0.1% = 3.68		P 5% = 1.28 P 1% = 1.82 P 0.1% = 2.63		P 5% = 1.23 P 1% = 1.75 P 0.1% = 2.53		P 5% = 2.94 P 1% = 3.98 P 0.1% = 5.31	

In 2023, most variants had significantly lower thousand seed weight (TSW) than the control, especially triticale (-8.47 g), soybean (-7.10 g), and sunflower (-4.63 g). In 2024, this trend reversed dramatically: soybean (+3.66 g), pea (+4.57 g), and sunflower (+2.27 g) showed significant increases. On average across years, only pea maintained a significantly positive effect (+1.55 g), while triticale continued to show a marked negative impact (-4.46 g) (Table 8).

Table 8. Influence of green manures on sunflower production in 2023 and 2024

	2023		2024	
Variant	Yield (kg/ha)	Difference/ significance	Yield (kg/ha)	Difference/ significance
Control	2051	Mt.	1813	Mt.
Rapeseed	2681	630*	2045	232**
Sunflower	2685	634*	2447	634***
Soybean	3060	1009**	2393	581***
Peas	3194	1143**	2741	929***
Triticale	2447	396^{ns}	2533	720***
	P 5%=559; P 1%=846; P 0.1%=1125		P 5%=203; P 1%=289; P 0.1%=418	

In 2023, the best results were obtained from soybean (3060 kg/ha) and pea (3194 kg/ha), with significant increases of 1009 kg/ha and 1143 kg/ha, respectively, over the control. Triticale yielded 2447 kg/ha, a non-significant difference from the control (-396 kg/ha).

In 2024, the control yielded 1813 kg/ha. Rapeseed showed an increase of 232 kg/ha. Pea had the highest yield (2741 kg/ha), with a highly significant increase of 929 kg/ha. Sunflower and soybean also showed large, statistically significant yield increases (634 kg/ha and 581 kg/ha, respectively). Triticale had the highest yield increase (3532 kg/ha), with a highly significant difference.

Influence of Green Manures on Maize Crop

Peas green manure was the only variant with a significantly negative effect on starch content, reducing it by 1.07% in 2023 (74.68% vs. 75.75% in the control) and by an average of 0.60% over two years (74.65% vs. 75.25%) (Table 9).

Table 9. The influence of chemical fertilizers on the starch content

Variant	2023		2024		Mean of years		Interaction of year	
	%	Dif./signif.	%	Dif./signif.	%	Dif./signif.	%	Dif./signif.
Control	75.75	Mt.	74.68	Mt.	75.25	Mt.	75.22	Mt.
Rapeseed	75.68	-0.07 ^{ns}	74.22	-0.47 ^{ns}	74.97	-0.28 ^{ns}	74.95	-0.27 ^{ns}
Sunflower	75.72	-0.03 ^{ns}	74.83	0.15 ^{ns}	75.28	0.03 ^{ns}	75.28	0.06 ^{ns}
Soybean	75.65	-0.10 ^{ns}	74.48	-0.20 ^{ns}	75.10	-0.15 ^{ns}	75.07	-0.15 ^{ns}
Pea	74.68	-1.07^{OOO}	74.55	-0.13 ^{ns}	74.65	-0.60 ^{oo}	74.62	-0.60 ^{O}
Triticale	75.53	-0.22 ^{ns}	75.22	0.53 ^{ns}	75.42	0.17 ^{ns}	75.37	0.16 ^{ns}
	P 5% = 0.46 P 1% = 0.66 P 0.1% = 0.95		P 5% = 0.59 P 1% = 0.84 P 0.1% = 1.22		P 5% = 0.36 P 1% = 0.52 P 0.1% = 0.75		P 5% = 0.46 P 1% = 0.62 P 0.1% = 0.83	

Influence on Thousand Kernel Weight

Triticale showed a consistently positive effect, with significant increases in 2023 (301.83 g, +14.50 g vs. control) and 2024 (290.00 g, +13.67 g), and a two-year average increase of +14.15 g. In contrast, rapeseed demonstrated a markedly negative effect, with significant reductions of -16.67 g in 2023 and -16.25 g on average (Table 10).

Table 10. The influence of green manures on the thousand kernel weight

Variant	2023		2024		Mean of years		Interaction of year	
	g	Dif./signif.	g	Dif./signif.	g	Dif./signif.	g	Dif./signif.
Control	287.33	Mt.	276.33	Mt.	281.80	Mt.	205.05	Mt.
Rapeseed	270.67	-16.67^{OO}	260.17	-16.17^{OO}	265.55	-16.25^{OO}	196.67	-8.38^{O}
Sunflower	279.00	-8.33 ^{ns}	268.50	-7.83 ^{ns}	273.75	-8.05 ^{ns}	200.77	-4.28 ^{ns}
Soybean	283.67	-3.67 ^{ns}	273.17	-3.17 ^{ns}	278.52	-3.28 ^{ns}	203.18	-1.87 ^{ns}
Peas	279.00	-8.33 ^{ns}	268.17	-8.17 ^{ns}	273.53	-8.27 ^{ns}	200.33	-4.72 ^{ns}
Triticale	301.83	14.50**	290.00	13.67*	295.95	14.15*	211.91	6.85 ^{ns}
	P 5% = 11.34 P 1% = 16.12 P 0.1% = 23.35		P 5% = 10.93 P 1% = 15.54 P 0.1% = 22.50		P 5% = 10.98 P 1% = 15.61 P 0.1% = 22.60		P 5% = 7.84 P 1% = 10.62 P 0.1% = 14.20	

Table 11. Influence of green manures on maize production in 2023 and 2024

	2023		2024	
Variant	Yield (kg/ha)	Difference/ significance	Yield (kg/ha)	Difference/ significance
Control	5464	Ct.	3290	Ct.
Rapeseed	8002	2538***	3468	179 ^{ns}
Sunflower	7280	1816***	3964	675 ^{ns}
Soybean	7789	2325***	4794	1504**
Pea	8432	2967***	4373	1083*
Triticale	6107	643**	6821	3532***
	P 5% = 372; P 1%=528; P 0.1%=764		P 5%=870; P 1%=1236; P 0.1%=1790	

As shown in Table 11, the control yield in 2023 was 5464 kg/ha. Rapeseed showed a highly significant increase of 2538 kg/ha. Sunflower (1816 kg/ha), soybean (2325 kg/ha), and pea (2967 kg/ha) all recorded highly significant gains, with pea reaching the highest yield (8432 kg/ha). Triticale yielded less (6107 kg/ha), but the increase of 643 kg/ha was statistically significant.

In 2024, the control yield was 3290 kg/ha. Pea had the highest increase (1083 kg/ha, statistically significant), followed by soybean (1504 kg/ha). Sunflower and rapeseed had moderate, non-significant increases (675 kg/ha and 179 kg/ha, respectively). Triticale recorded the highest increase (3532 kg/ha), with a highly significant positive difference.

Conclusions and recommendations

The selection of green manure species should consider their impact on soil reaction and nutrient mineralization capacity. Rapeseed and sunflower proved to be the most suitable for correcting soil acidity and maintaining a stable agrochemical balance. The use of pea as a green manure is recommended to improve wheat quality, while chemical fertilization remains essential for ensuring a competitive yield level. The general conclusion is that sunflower responds favorably to green manures with weed-suppressing effects (rapeseed, triticale); however, harvest quality can vary considerably, requiring careful selection of the agricultural practice combination. Maize benefits from crop rotations preceded by species with high organic matter input and biological nitrogen fixation capacity, such as pea and sunflower. The use of these species as green manures is justified both agrochemically and economically.

In areas with acidic soils and low fertility, the systematic integration of green manures, combined with moderate chemical fertilization and crop rotation, represents a sustainable and effective strategy for long-term improvement of soil quality and agricultural performance.

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