
SUMMARY OF THE DOCTORAL THESIS

The role of green manures in improving the fertility levels of acidic soils in northwestern Romania

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INTRODUCTION

The combined use of chemical and organic fertilizers represents a promising approach for the rapid correction of nutrient deficiencies and the improvement of soil structure. The adaptation and application of this approach according to the specific needs of the soil and crops enhances the benefits of both types of fertilizers, contributing to the sustainable increase of agricultural production. The use of green manures and cover crops brings multiple advantages, including the reduction of soil water evaporation, prevention of erosion, maintenance of optimal soil temperature, and improvement of soil structure. When incorporated into the soil, green manures release essential nutrients. A landmark research article highlighted the increase in organic carbon content and the improvement of soil structure following the application of green manures. These amendments can stimulate the activity of beneficial soil microorganisms. Researchers have reported an increase in microbial biomass in soils treated with green manures.

1. Structure of the Doctoral Thesis

The doctoral thesis consists of a total of 132 pages and is structured into two parts:

- Current State of Knowledge – Part I (39 pages)
- Personal Contribution – Part II (93 pages)

The second part of the thesis comprises 93 pages, which are organized into 6 chapters. This part presents the research objectives, description of the experimental area, materials and methods, the obtained results and discussions, conclusions, and recommendations based on the results, as well as the originality and innovative contributions of the thesis.

2. Objectives

The main objective of the research is to determine the effects of green manures and their combinations with chemical fertilizers on soil fertility and major agricultural crops (wheat, maize, sunflower).

In this context, the following objectives were established for the development of the doctoral thesis:

- To determine the effect of green manures on soil nutrient content
- To evaluate the influence of green manures on soil pH
- To analyze the impact of green manures on weed infestation levels in major crops

- To determine the effect of green manures on the occurrence of plant diseases and pests
- To assess the impact of green manures on the quality indicators of major crops
- To determine the influence of green manures on the yield of major crops

3. Material and method

The experiment was conducted on the experimental fields of the Agricultural Research and Development Station (SCDA) Livada 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 cultivated plant.

The experiment was carried out according to the split-plot method, with three replications, and involved three main experimental factors:

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 Nitrocalcar ($\text{NH}_4\text{NO}_3 + \text{CaMg}(\text{CO}_3)_2$), applied at a rate of 450 kg/ha, with two levels:

- B1 – Chemically fertilized
- B2 – Not chemically fertilized

Factor C was applied only to the wheat crop and involved fungicide treatment, using a combination of active substances: prothioconazole 53 g/L, spiroxamine 224 g/L, and tebuconazole 148 g/L. The application dose was 0.750 L/ha, applied in two phenological stages. Factor C had two levels:

- C1 – Untreated
- C2 – Treated

4. Results and discussion

4.1. Determination of Biomass and Nitrogen Content in Green Manure Crops

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

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

4.2. Evolution of Agrochemical Properties of the Soil

Rapeseed, 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, showing lower pH levels, especially in the first year.

The results indicate that green manures, when combined with chemical fertilization, can enhance soil fertility—especially in the case of species like sunflower and soybean. However, the efficiency varies depending on the species and treatment.

In 2023, the fertilized control (F) recorded higher values of total nitrogen (N_t , 0.163%) and humus (1.66%) compared to the unfertilized control (N). Fertilized green manures such as soybean (F) had a significantly positive impact, with elevated values of N_t (0.150%) and humus (1.59%). On the other hand, unfertilized pea (N) exhibited the lowest content of 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 values of 0.153% and humus content of 1.69%, underlining its beneficial role. In contrast, the fertilized control (F) showed a significant decrease in N_t (0.065%), suggesting a possible depletion of soil nitrogen. Additionally, fertilized triticale (F) displayed low values of N_t (0.054%) and humus (1.58%).

4.3. Influence of Green Manures on the Wheat Crop

4.3.1. Influence on Weed Infestation

Rapeseed appears to exhibit allelopathic properties that inhibit weed germination, with a similar but more moderate effect observed in pea. In contrast, the control variant showed intermediate weed levels. The dominant species was *Cirsium arvense*, representing 40% of the total weed population, followed by *Stellaria media* (24%) and *Convolvulus arvensis* (17%). Other species, such as *Gypsophila paniculata* (8%), *Raphanus raphanistrum*, and *Apera spica-venti* (each 5%), were less prevalent, while *Matricaria inodora*, *Viola arvensis*, and *Galium aparine* were nearly absent.

4.3.2. Influence on Protein Content

Results from 2023 show that, compared to the control, only the green manure variant with pea recorded a significantly positive difference in protein content. The other variants did not exhibit statistically significant differences. In 2024, the control variant showed 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 between variants. However, considering year interaction effects, the green manure variant with pea showed a significantly positive difference, reaching a protein content of 11.09% in the wheat crop.

4.3.3. Influence on Gluten Content

Pea stood out with a consistently positive effect, showing significantly higher gluten content both 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 in both years of the study.

4.3.4. Influence on Hectoliter Mass

Regarding hectoliter mass, pea produced the most consistent positive results, with a significantly higher average value (74.38 kg/hl) compared to the control (73.54 kg/hl). On the other hand, triticale had a significant negative impact, showing substantially lower values in 2023 (67.54 kg/hl) and in the two-year average (70.63 kg/hl).

4.3.5. Influence on Thousand Kernel Weight (TKW)

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 exhibited negative tendencies, with lower average values (42.78 g and 42.30 g, respectively) compared to the control (43.46 g), although statistically significant differences were observed only under certain conditions. Sunflower recorded a slight, non-significant increase (43.68 g).

4.3.5. Influence on Diseases and Pests in Wheat

In the wheat crop within the experimental area, the pathogen complex was divided into three categories: root and stem base diseases represented by *Cercospora herpotrichoides*, foliar diseases (*Septoria* spp.), and ear diseases (*Cladosporium herbarum*).

The highest infection rate of *Cercospora* was recorded in the triticale variant, with an average value of 24.63%, which was 8.91% higher than the control and statistically highly significant. The lowest infection rate was observed in the soybean variant, with a difference of -2.41%, which was not statistically significant.

Regarding ear infections by *Cladosporium* spp., only the control variant showed a minor reduction of -0.02%, which was not significant. The highest infection level was recorded in the triticale variant (14.28%).

Results indicated a very weak correlation ($R^2 = 0.034$) between leaf desiccation and infection level by *Septoria* spp. on leaves 1–3, suggesting that the desiccation level is not strongly influenced by the pathogen.

4.3.6. Influence of Green Manures on Wheat Yield

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 significantly negative results for soybean (-396 kg/ha). Only the pea variant showed a non-significant yield reduction (-115 kg/ha).

4.4. Influence of Green Manures on Sunflower Crop

4.4.1. Influence on Weed Infestation

The highest weed density was recorded in the unfertilized control variant (126 plants/m²), followed by the sunflower green manure variant (100 plants/m²). Rapeseed and triticale showed the lowest weed densities in unfertilized variants (43 and 31 plants/m², respectively), indicating a beneficial weed-suppressing effect. Chemical fertilization increased weed infestation across all variants. The dominant species was *Chenopodium album* (74%), followed by *Ambrosia artemisiifolia* (12%). Other species, including *Raphanus raphanistrum*, *Apera spica-venti*, *Convolvulus arvensis*, *Cirsium arvense*, and *Echinochloa crus-galli*, represented between 1–3%.

4.4.2. Influence on Diseases and Pests

Septoria helianthi was the most prevalent pathogen in sunflower. Infection severity peaked in the unfertilized control (73.5%), while the lowest incidence was

observed in the unfertilized rapeseed variant (40%). The highest average infection level was recorded in the pea green manure variant, in both fertilized and unfertilized forms, exceeding a mean attack degree of 70%.

4.4.3. Influence on Fat Content

Triticale and soybean had the most notable effects in 2023, significantly increasing fat content to 47.40% and 46.77%, respectively, compared to the control (44.38%). Rapeseed maintained fat content values above the control in both 2023 (45.72%) and 2024 (44.60%), though without reaching statistical significance.

4.4.4. Influence on Hectoliter Mass

Rapeseed and soybean showed consistently negative effects on hectoliter mass, with significantly lower values than the control in both 2023 and the multi-year average. Rapeseed recorded an average reduction of 0.83 kg/hl (41.53 kg/hl vs. 42.37 kg/hl), while soybean showed a similar decrease of 0.92 kg/hl.

4.4.5. Influence on Thousand Seed Weight

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

4.4.6. Influence on Sunflower Yield

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.

4.5. Influence of Green Manures on Maize Crop

4.5.1. Influence on Weed Infestation

The control variant exhibited the lowest weed density, with similar values for fertilized and unfertilized conditions (42–45 weeds/m²). Green manures generally led to increased weed pressure. Rapeseed showed a slight increase (55–60 weeds/m²), with moderate differences between treatments. The sunflower variant showed a sharper increase, particularly in the unfertilized plots.

The weed flora composition was dominated by annual species, primarily *Echinochloa crus-galli* (41%) and *Chenopodium album* (31%), followed by *Eriochloa villosa* (11%). Among perennials, *Equisetum arvense* (7%) and *Cirsium arvense* (6%) were present in significant amounts, known for their resistance to control without an integrated management strategy.

4.5.2. Influence on Diseases and Pests

The impact of green manures on *Fusarium* spp. in maize ranged from 0.87% in the pea variant to 1.36% in soybean. For *Ostrinia nubilalis* infestation, values ranged from 40% (pea) to 55% (soybean). Although differences were observed between treatments and the control, none were statistically significant, indicating a limited effect of green manures on these parameters.

4.5.3. Influence on Starch Content

Pea 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%).

4.5.4. Influence on Hectoliter Mass

Pea had a consistently negative effect, with significantly lower values both in 2023 (68.03 kg/hl vs. 69.38 kg/hl in the control) and over the two-year average (67.08 kg/hl vs. 68.20 kg/hl).

4.5.5. Influence on Thousand Kernel Weight

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

4.5.6. Influence on Maize Yield

In 2023, the control yield was 5464 kg/ha. Rapeseed produced 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.

5. Conclusions and recommendations

5.1. Conclusions Regarding the Influence of Green Manures on the Evolution of Agrochemical Soil Properties

The selection of green manure species should be made considering 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.

5.2. Influence of Green Manures on the Wheat Crop

The use of pea as green manure is recommended for improving wheat quality, while chemical fertilization remains essential for ensuring a competitive yield level.

5.3. Influence of Green Manures on the Sunflower Crop

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.

5.4. Influence of Green Manures on the Maize Crop

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.

5.5. Recommendations

For 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.

6. Originality and innovative contributions of the thesis

This thesis stands out through a series of original elements and innovative contributions, both theoretical and practical-applied, within the context of sustainable agriculture and the restoration of soil fertility in the acidic soils of northwestern Romania.

The comparative application of various green manure species (rapeseed, sunflower, pea, soybean, triticale) under the specific pedoclimatic conditions of the Livada area (Satu Mare County) represents an original contribution due to its systematic and contextual character. The comprehensive evaluation of the influence of green manures on the evolution of soil pH, total nitrogen content, humus, and organic carbon, alongside crop quality parameters (protein, gluten, hectoliter mass, and thousand kernel weight), provides an integrated perspective that is rarely encountered in applied studies conducted in Romania.

The modeling of relationships between pH and total nitrogen, as well as organic carbon, through polynomial equations constitutes a methodological contribution, offering useful tools for forecasting soil agrochemical behavior depending on the applied agricultural management. The demonstration of the value of combined fertilization in maintaining soil stability and crop yield under conditions of naturally low fertility further enhances the thesis's practical relevance.

By integrating theoretical knowledge with field observations and rigorous statistical analysis, this research makes a clear contribution to the scientific validation of the role of green manures in natural resource regeneration, reinforcing their position as a viable alternative to exclusive mineral fertilization.