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Evaluation of the role of common vetch (*Vicia sativa* L.) green manure in crop rotations

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SUMMARY

Common vetch (Vicia sativa L.) is an annual legume, grown as green manure provide rapid soil cover, can increase soil moisture and organic matter content and reduce soil erosion during fall. During the fallow period, legumes grown as catch crops are known by releasing large amounts of mineral nitrogen (N) for the subsequent crop. By taking advantage of these benefits, it is possible to increase the yield of the next crop in an environmentally friendly and sustainable way. The goal of this study was to determine the value of common vetch as a green manure, considering its effect on soil conditions and the yield of next crops. We examined three different common vetch seed rate as a green manure in a crop rotation with triticale, oat and corn. Next to the green manured treatments, we used fertilized and bare fallow control treatment for comparison. In our study we evaluated the aboveground biomass weight of spring vetch green manure and its effect on the moisture content of the soil. We examined the green manure's effect on the next crops plant height and yield. We found that the moisture content of the green manured plots was significantly higher during summer drought. On the green manured plots, 37.9% higher triticale yield, 50% higher oat yield and 44% higher corn yield were measured compared to the control plots. The insertion of spring vetch green manuring into crop rotations could be a good alternative to sustainable nutrient replenishment methods. It can be used to reduce the input needs of farming, reduce carbon footprint, contribute to the protection of soils and increase the organic matter content of the soil.

Keywords: *common vetch; catch crop; green manure; soil moisture; yield*

INTRODUCTION

The large decrease in soil organic matter content and the negative changes in its structure can be explained by the decrease of the intake of organic matter and the biological activity of the soil, as well as the crop rotation contains fewer and fewer plant species. There is a tendency in crop production, that the soil is cultivated intensively only at a certain time of the year to grow an economically beneficial crop, but the procedures taken to optimize the soil condition after the crop is harvested are often insufficient or non-existent. One of the key issues for the sustainability of crop production in the 21st century is what special agronomic practices are developed by the agriculture, especially with regard to the significant increase in fertilizer prices. Nemecek et al. (2008) are of the opinion that the crop rotation of intensively cultivated areas with a high proportion of cereals and in areas where intensive nitrogen fertilization is used, the cultivation of legumes can reduce energy demand, global warming potential, ozone formation and acidification, and the ecological footprint of cultivation. The advantages are that the cultivation of legumes requires less nitrogen fertilizer, the next crop will have a lower need for nitrogen fertilizer. Due to the better condition of the soil, the energy requirements of tillage can be reduced, it also provides an opportunity to diversify crop rotations, which can reduce the proliferation of certain weeds and pathogenic species, thereby reducing the amount of pesticides applied.

The unique ability of leguminous green manure plants to sequester atmospheric nitrogen using *Rhizobium* bacterias at their roots, in addition, their ability to produce biomass and nutrients is significant, making them one of the most widely studied groups of crops in agro-ecosystems worldwide. Many authors suggest the use of catch crops/green manure with nitrogen-fixing plant species, instead of fallow as an alternative to remediation of degraded soils (Biederbeck, 1990; Wright, 1990; Campbell et al., 1991). Cover crops also perform their function as green manure by making the nitrogen they take up from the soil easily available to the next crop after rotation into the soil (Kramberger et al., 2009; Justes et al., 2012).

Species belonging to the genus *Vicia* allow multiple uses, the common vetch (*Vicia sativa* L.) can be classified as an alternative plant (Francis et al., 1999). Common vetch species grown as fodder or green manure provide rapid soil cover, exhibiting their weed-suppressing ability (Uzun et al., 2004). Until the 1960's, common vetch was grown in a significant area in Hungary (Vágó, 1981). However, with the radical reduction of livestock, the production area has decreased mainly for seed production and export. Common vetch variety (Emma) used in our studies received state registration in 2005, the main objectives of its breeding were rapid initial development, high leaf mass, high green mass, and resistance to fungal and viral diseases (Szabóné, 2003).

The spring or common vetch (*Vicia sativa* L.) is an annual legume. German, French and Russian researchers began to deal with its tendentious breeding in the 1890's, in Hungary, the selective breeding began in 1921 (Késmárki, 2005). It has a bushy shoot system, 60–140 cm long stems, and its roots develop richly branched lateral roots, which penetrates 90–110 cm deep (Szabóné, 2010).

According to Tonitto et al. (2006), legumes are the most efficient value for green manure due to their C:N ratio (10–15:1), which allows faster mineralization, furthermore plant residues rotated into the soil contain higher amounts of nitrogen uptaked by the plant. Sainju and Sing (1997) have a similar view that common vetch

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residue can decompose rapidly in the soil due to its high N concentration and low C:N ratio.

Soil condition optimization is also reflected in more favorable soil moisture values. Wang et al. (2020) examined the effect of spring vetch and oat green manure crops on soil water balance in crop rotation with winter wheat and corn. In their studies, the soil of the area treated with pure spring vetch green manure had a significantly higher moisture content when the green manure plants were turned into the soil than the soils treated with pure oats and oat-vetch mixture. Vetch can also improve soil water quantity compared with bare fallow by reducing erosion during fall, winter, spring, and increasing organic matter content (Sainju and Sing, 1997).

Couëdel et al. (2018) examined different leguminous green manure plant species, they established that spring vetch acquired the most amount of N (76 kg N ha^{-1} and 161 kg N ha^{-1}, depending on the location) between the tested leguminous plants. According to Bayer et al. (2000), a legume cover crop, such as common vetch, can supply most of the N required for maximum corn yield. It also should be noted that the use of catch crops can also have a negative effect on the soil's ability to provide moisture to the crop following the green manure, given the extra water demand during plant development, especially in semi-arid and arid areas where rainfall is often limited (Unger and Vigil, 1998). However, due to high nitrogen sequestration and significant biomass production, with adequate rainfall, common vetch can increase the yield of the next crop in the crop rotation. In the experiment of Ozpinar (2009), the biomass yield of the spring vetch green manure crop varied between 2.92 and 6.26 t ha^{-1}, grown in rotation with corn depending on the cropyear. According to the experience of Hargrove (1986), the common vetch green manure plant produced a biomass weight of 4.3 t ha^{-1}, compared to rye used as a green manure crop, sorghum sown as a main crop produced a yield of 3.7 t ha^{-1} after vetch green manure, while yielded only 2.6 t ha^{-1} after rye green manure. During the growing season of common vetch, it admitted 134 kg ha^{-1} of N, while rye admitted only 38 kg ha^{-1}. According to Hargrove's (1986) calculations, the value of spring vetch green manure corresponds to 61 kg ha^{-1} N fertilizer. In experiment of Touchton et al. (1984), common vetch produced 4.9 t ha^{-1} biomass weight and enriched the soil with 118 kg ha^{-1} of N after tillage. In this experiment the subsequent crop reached 25% higher yield compared to bare fallow.

The aim of our research is to assess the performance of common vetch as a green manure crop in a crop rotation system, taking into account its effect on the soil moisture content and the forecrop value with triticale, oats and corn as indicator crops. In our research, we evaluated the biomass yield of spring vetch sown with 3 different plant densities, and we evaluated the subsequent crops' average height and yield in the cases of green manure, fertilization and control treatments.

MATERIALS AND METHODS

Experimental area

We set up our experiment at the area of Research Institute of Nyíregyháza (RINY) Institutes for Agricultural Research and Educational Farm University of Debrecen. The soil type of the experimental area is sandy soil with humus, the pH of the soil is neutral (7.3), the value of plasticity index according to Arany is 28.9–30.2 K_A. The organic matter content of the area is 0.9–1.2%. The phosphorus and potassium contents range the soil into the well supplied and the adequately supplied categories, respectively (*Table 1*).

Table 1: **Soil chemical analysis of the experimental area (Nyíregyháza, 2020)**

Soil depth [cm]	0–25	25–50
pH (KCl 1:2.5) [-]	7.3	7.3
Plasticity index according to Arany [K_A]	28.9	30.2
Total soluble salt content [m/m%]	<0.02	<0.02
Carbon content [m/m%]	0.8	1.3
Organic matter content [m/m%]	1.2	0.9
Nitrogen-nitrite+nitrate (KCl soluble) [mg kg^{-1} d.m.]	3.0	1.4
Potassium-oxide (AL-soluble) [mg kg^{-1} d.m.]	211.0	156.8
Phosphorus-pentoxide (AL-soluble) [mg kg^{-1} d.m.]	170.0	113.1

Experimental design

The experiment was set up in a randomized block design in the autumn of 2019. The experiment involves a complex crop rotation system consisting of three blocks, the different blocks are characterized by different plant orders (*Table 2*).

Table 2: **Plant order of the 3 blocks involved in the experiment**

Year	Block I.	Block II.	Block III.
2020/I	Triticale	Oat	Triticale
2020/II	Catch crop - Common vetch	Catch crop - Common vetch	Catch crop - Common vetch
2021/I	Corn	Triticale	Oat

The plants involved in the crop rotation were triticale (x *Triticosecale* conv. Szabolcs), oats (*Avena sativa* conv. Lota) and corn (*Zea mays* conv. DKC 4943). A Wintersteiger Plot Spider plot seeder was used for sowing, and a Zürn 130 SE plot combine was used for harvesting the subsequent cash crops. In the autumn of the first year of the experiment (2019), the RINY's own triticale variety was sown on the plots of the Blocks I. and III., followed by the sowing of oat variety Lota in Block II. in spring. The cereals were sown with standard seed doses (triticale: 4 million seeds ha^{-1}, oats: 4.5 million seeds ha^{-1}) and conventional cultivation

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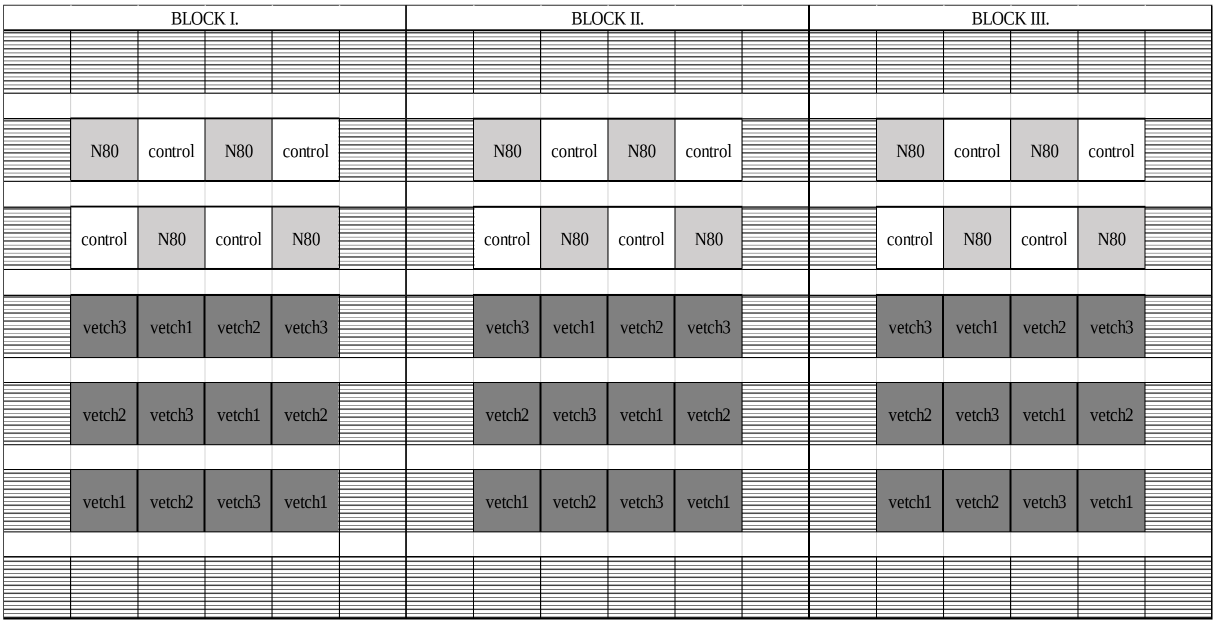
technology was applied. After harvesting the cereals (triticale: 30/07/2020; oats: 07/08/2020), the soil tillage was done with a disc harrow and the seedbed was prepared for the green manure plant with a harrow. The common vetch variety (*Vicia sativa* L. conv. Emma) of the RINY was sown as a green manure plant on 11/08/2020 in all the three blocks.

The plot of the experiment is illustrated in *Figure 1*. The treatments are applied in 4 replicates, the experimental plots are bordered in all directions. The experimental plots are all 1.7 x 9.2 m in size. In addition to the green manure treatments, control treatments (without the use of green manure and fertilizer) and fertilized plots were used in the experiment. Fertilization was applied only on those plots which got fertilizer treatment during the growing season of the indicator plants in spring, as a top fertilizer, uniformly in the form of 80 kg ha^{-1} N active ingredient. The applied seed doses of the common vetch green manure were: 2 million seeds ha^{-1}; 2.5 million seeds ha^{-1} and 3 million seeds ha^{-1} in plots marked “vetch1”, “vetch2” and “vetch3”. The fertilized and control plots functioned as a bare fallow between the growing seasons of the two main plants.

Figure 1: **Plot map of the treatments used in the experiment**



Note: Plots with catch crop treatment: vetch1 – seed dose: 2 million ha^{-1}; vecth2 – seed dose: 2.5 million ha^{-1}; vetch3 – seed dose: 3 million ha^{-1}. Control: no catch crop, no fertilizer. N80: no catch crop, fertilizer: 300 kg ha^{-1} MAS (mono ammonium sulphate).

The green manure plant was cut with a forage crimper before flowering, and then incorporated into the soil with a disc harrow (28/10/2020). After seed bed preparation, triticale was sown in the Block II. (30/10/2020), then in spring oat was sown in the Block III. (16/03/2021) and corn wan sown in the Block I. (15/04/2021).

Climatic characterization of the crop seasons

The precipitation and average temperature data of the studied crop seasons are illustrated in *Figure 2*, compared with the average values of the last 30 years recorded in the region. The amount of precipitation during the sowing period of green manure crops was below the average in August, however, September and October were proved to be very rainy (72.3 mm, 103.5 mm), much above the 30-year averages (43 mm, 44 mm), hence provided optimal conditions for green manure plants to develop vegetative biomass, which was also associated with the fact that the daily average temperature values also exceeded the average of the recent years. In turn, the high amount of precipitation hindered the implementation of the autumn soil works and sowing. Both the precipitation and the average temperature of the winter months exceeded the average values, the water resources of the soil were replenished. In April and May, there were 59.7 mm and 90.6 mm precipitation, respectively, which was favorable for spring-sown crops, but lower than the usual temperatures impeding the germination and initial development of corn. In June and July, there was very low amount of precipitation, which was associated with high evapotranspiration values and high number of hot days (daily average temperature above 25 °C) (June: 6 hot days, July: 12 hot days). The weather was not without extremes, the water retention and storing capacity of the soil played an important role in the optimal development of the plants.

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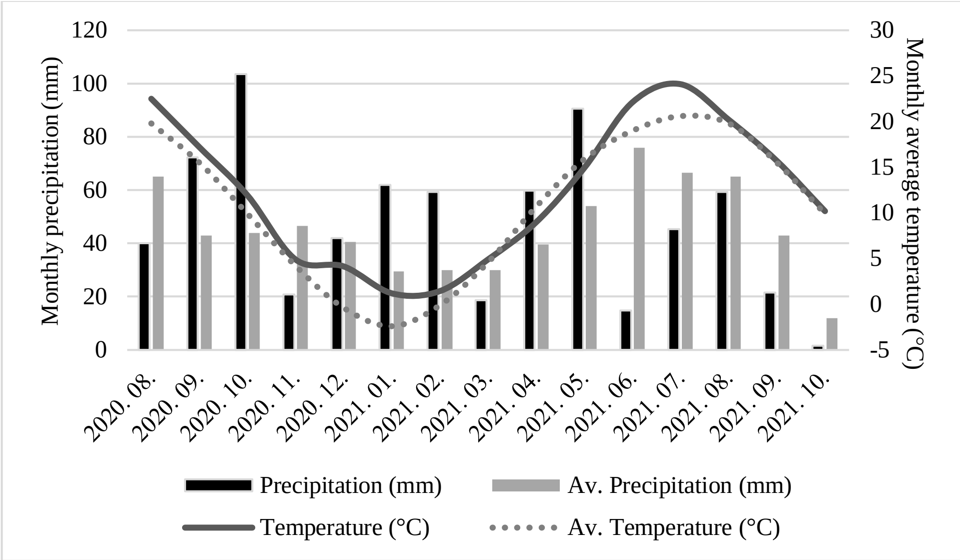
Figure 2: **Precipitation and average temperature data of the studied crop seasons in comparison with the averages of the last 30 years**



Methods of sample collection

Soil sampling

Homogenous soil samples were taken with a hammer system soil sampler to the depth of 1 m (0–25 cm, 25–50 cm, 50–75 cm, 75–100 cm) with a 5 cm diameter sampling tube. The moisture content of the soil samples was determined gravimetrically and expressed by in weight percentage. The dates of the soil sampling were as follows:

- 22/10/2020: Before green manure termination. Amount of precipitation in 20 days before sampling: 82 mm.
- 19/05/2021: Triticale – appearance of flag leaf; Oats – tillering; Corn – 4 leaf stage. Amount of precipitation in 20 days before sampling: 68.4 mm.
- 01/07/2021: Triticale – end of flowering; Oats – end of flowering; Corn – inflorescence emergence. Amount of precipitation in 20 days before sampling: 11.9 mm.

Plant biomass sampling

All above-ground biomass of common vetch catch crop was collected from 0.25 m^2 per replicate. Plant biomass samples were collected prior to the rotation of the green manure plant into the soil (28/10/2020).

Evaluation of yield parameters of indicator crops

In the case of cereal plants (triticale, oats), plant height was evaluated at the end of flowering. Plant height was determined by a measuring rod, measuring 3 average values in stand per replicates. In the case of yield, we measured the weight of the harvested grains from each plot then converted it to tonnes ha^{-1}.

Statistical analysis

SPSS software (ver. 26, IBM, USA) was run to compare the means and analyze the variance among treatments, followed by Tukey’s post hoc analysis to indicate the significant differences where applicable

RESULTS AND DISCUSSION

Soil moisture dynamics

In October, soil sampling took place the growing season of the common vetch green manure terminated. During that period, a significant amount of precipitation fell (103.5 mm in October). No significant differences were found in the soil moisture contents at the depth of 100 cm: the soil moisture content was between 13.88% and 19.34% in the cases of the areas treated with green manure, and between 8% and 22.31% in the cases of bare fallow areas. There was a tendency that in the cases of green manured soils, the moisture content of the soil in the deeper layers (50–75 cm, 75–100 cm) were higher than in the cases of bare soils. Consequently, the use of green manure allowed soil moisture to pass into deeper layers, ensuring an even distribution of moisture in the soil profile (*Figure 3*).

At the time of sampling in May, the moisture content of the soils with the different subsequent crops was examined in order to determine whether the after-effect of the green manure plant could be detected. Due to the precipitation of 59.7 mm in April and 90.6 mm in May, the moisture content of the soils was optimal, we could not detect significant differences within the blocks between the different treatments.

In Block I., with corn, the soil moisture content of the areas treated with green manure in the upper 35 cm layer of the soil was lower than in the case of the control treatment, however, in the deeper soil layers the soil moisture content was more favorable than in the control (*Figure 4*).

In block II., with triticale crop, the moisture content of the green manured soils – especially in the deeper layers – proved to be higher than in the case of the control treatment (*Figure 5*).

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Figure 3: **Average soil moisture contents in the green manure treated and the untreated control blocks in October**

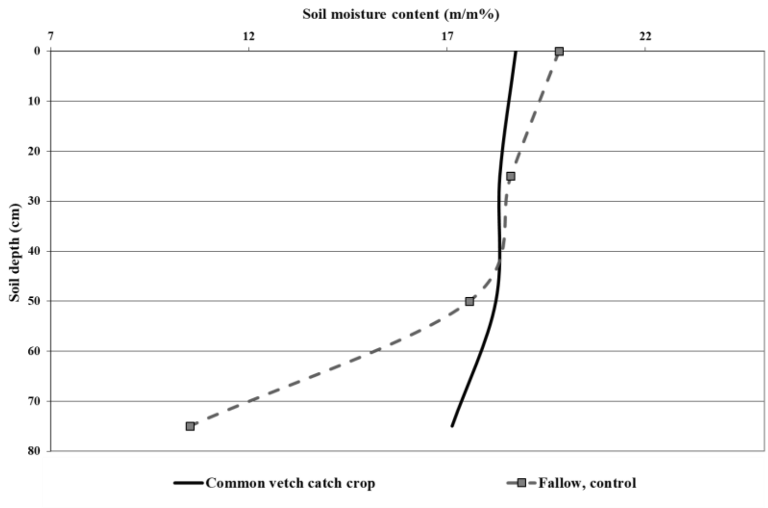


Figure 4: **Soil moisture content in corn stand in the green manure and control treatments in May**

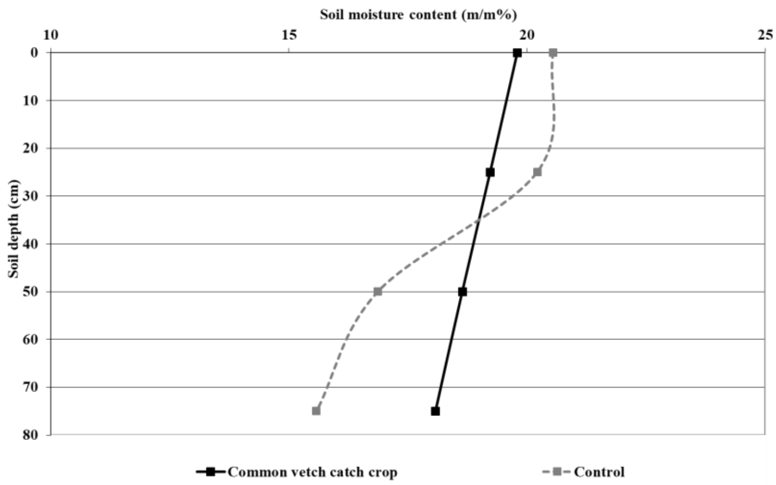
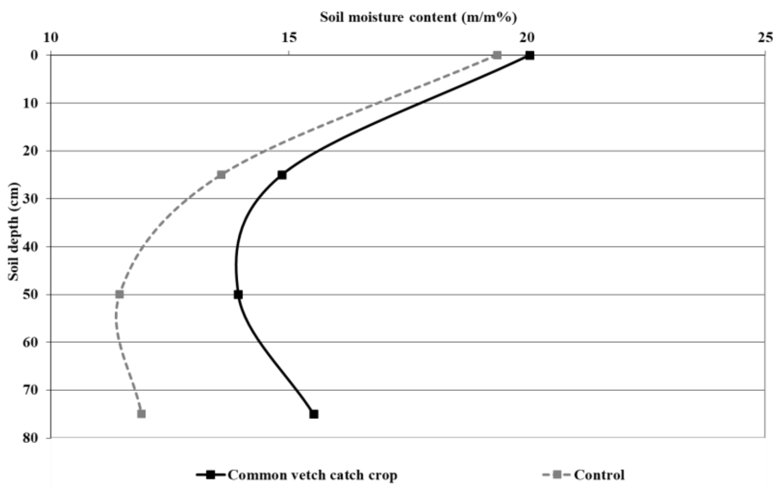


Figure 5: **Soil moisture content in triticale stand in the green manure and control treatments in May**



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In block III., with oat, the soil moisture content of the control areas was a bit higher in the upper layer of the soil, however, in the soil layer deeper than 40 cm, the soil of the green manured areas also had a higher moisture content than the control areas (*Figure 6*).

Before the sampling on 1st July, only 14.9 mm of precipitation fell in June with an evapotranspiration rate of 157.6 mm/month. In the drought month, 6 hot days (average daily temperature above 25 °C) were measured, the top layer of the soil had lost a large amount of its moisture content. In the triticale stand (Block II.), a significant difference in moisture content was found in the 25–50 cm, 50–75 cm, and 75–100 cm layers of the soil in the favor of the green manured plots (*Figure 7*).

Figure 6: **Soil moisture content in oat stand in the green manure and control treatments in May**

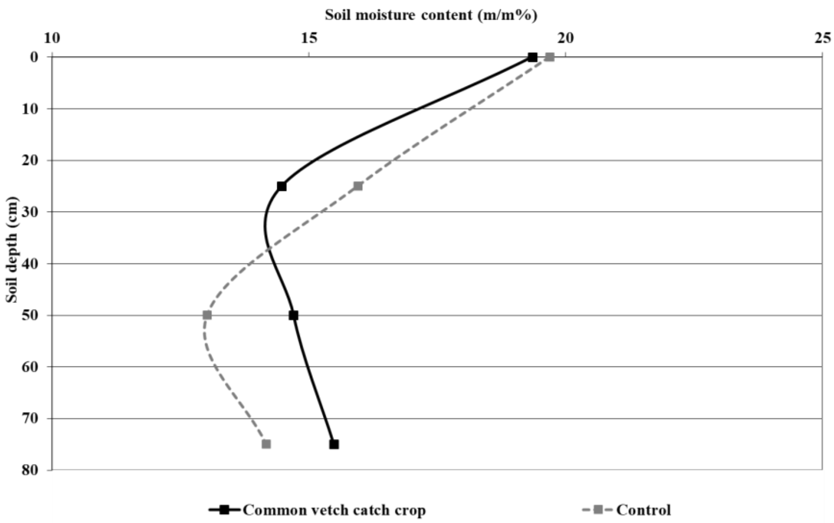
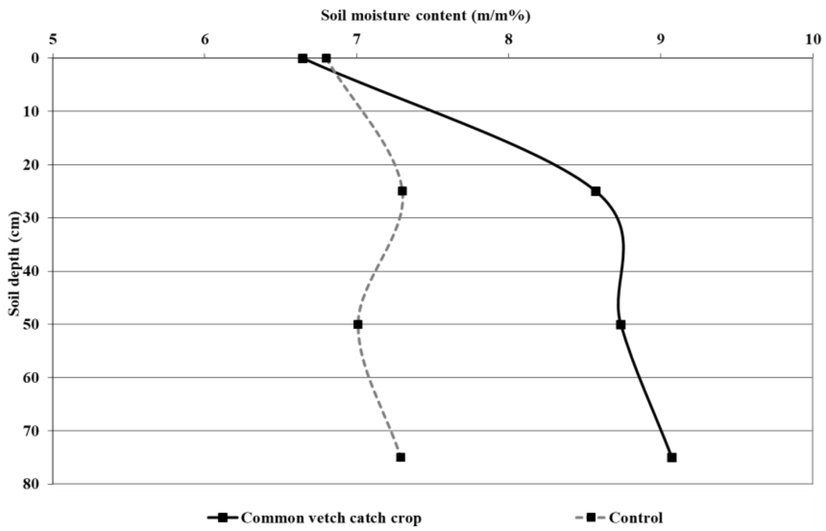


Figure 7: **Soil moisture content in triticale stand in July in the green manure and control treatments on 1st July**



In the case of the samples taken from the soil of the oat stand (Block III.), a similarly higher moisture content was observed, the green manured plots resulted in a significantly higher moisture content in the upper 50 cm layer of the soil (*Figure 8*).

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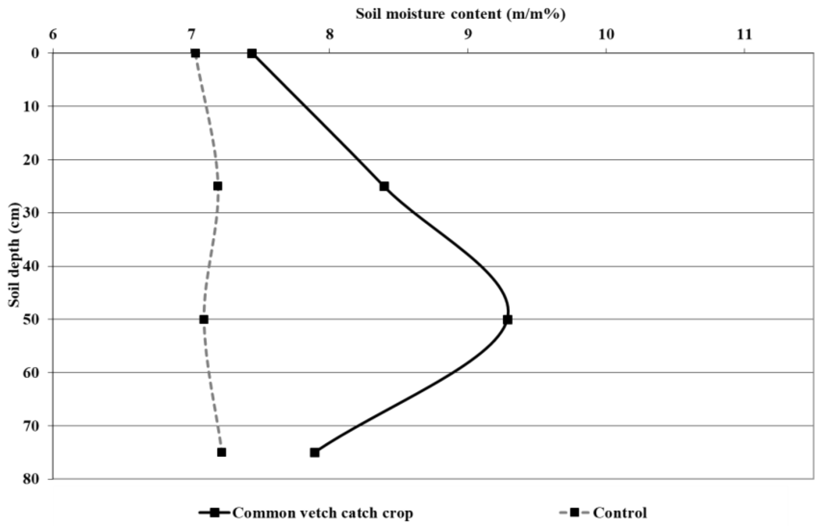
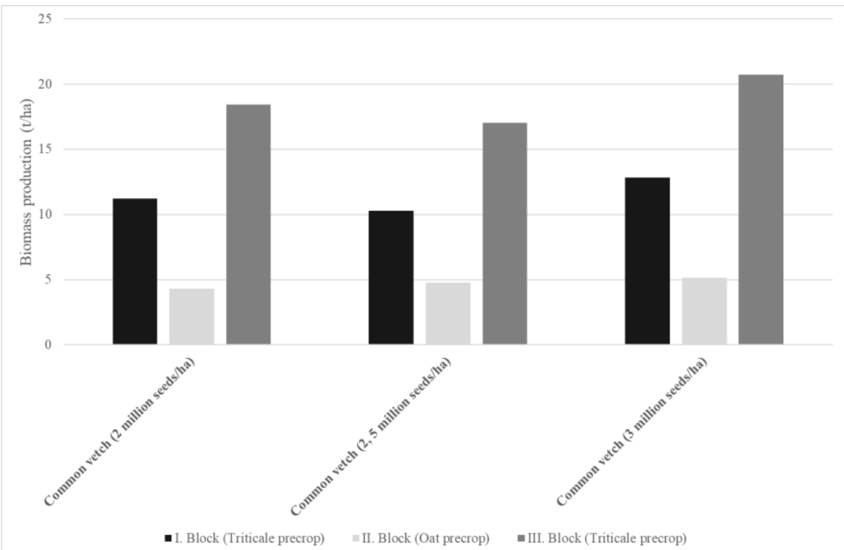
Figure 8: **Soil moisture content in oat stand in the green manure and control treatments on 1st July**



Evaluation of green manure biomass

We collected the aboveground biomass of the common vetch before green manure was terminated. The above-ground biomass was significantly different between blocks with the different forecrops, due to the aggressive root system of oats, the higher water consumption and the significant amount of stem residues. It resulted lower soil moisture content, thus slower germination, and hindered the development conditions for the green manure crop, which produced significantly lower green yields. No significant difference in green yields was observed in common vetch with different seed densities. In case of oat forecrop, we detected tendentiously higher amount of green mass in case of higher amount of common vetch seed dose. In the case of triticale forecrop, the highest green yield was obtained at a seed dose of 3 million seeds ha^{-1}, followed by seed dose of 2 million seeds ha^{-1} and then seed dose of 2.5 million seeds ha^{-1}. Regarding the average values, the common vetch produced 10.3–20.7 t ha^{-1} green yield in the case of triticale forecrop and 4.3–5.2 t ha^{-1} green yield in the case of oat forecrop (*Figure 9*).

Figure 9: **Aboveground biomass production of common vetch green manure in terms of different seed densities and forecrops**



Effect of green manure on plant height of triticale and oat

Plant height studies showed a statistically proven positive effect of green manure on the indicator plants, which almost reached or exceeded the effect of nitrogen fertilization at the dose of 80 kg ha^{-1} in terms of the trait. In triticale (Block II.) no significant difference was observed in the cases of the different doses of green

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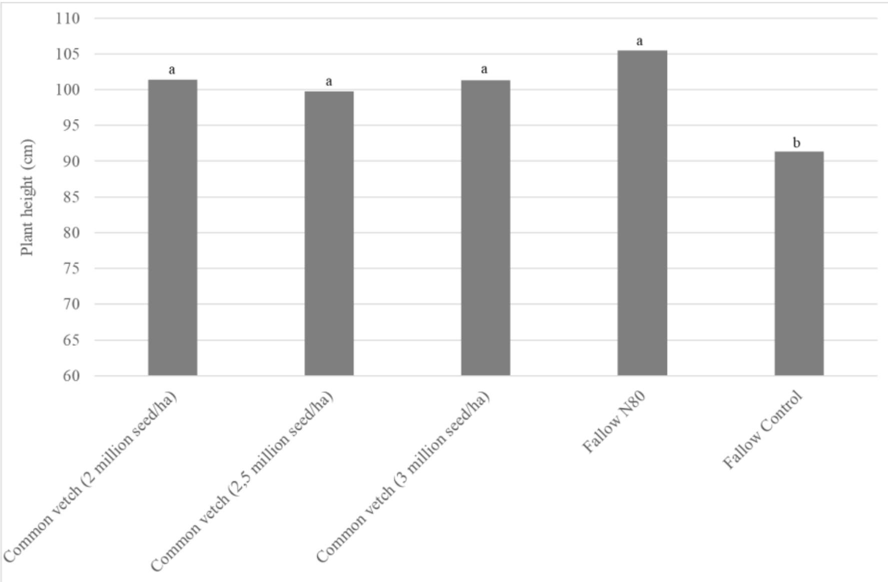
manuring, however, plant height of the green manured plots neared the value of the fertilized treatment and significantly exceeded the values measured in the control areas (*Figure 10*). The average plant height of triticale was 100.8 cm after common vetch green manuring, 105.5 cm in the fertilized plots, and 91.3 cm in the control plots.

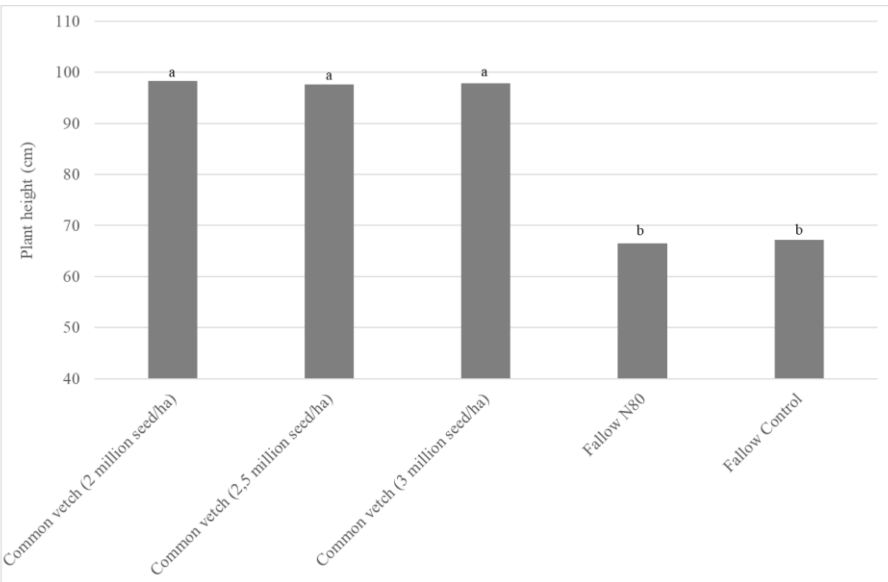
Figure 10: **Triticale plant height measured in July in terms of the different green manure and fertilization treatments**



Values with different letters are significantly different at the 95% confidence level by Tukey's test.

In case of the measurements in oat, there was no verifiable difference between the effects of green manure doses, however, significantly higher plant height values were measured compared to the results of the fertilized and control areas (*Figure 11*). The average plant height was 97.9 cm for the green manured plots, 66.5 cm for the fertilized plots and 67.2 cm for the control treatments, and no significant difference was found between the fertilized and control treatment's plant height.

Figure 11: **Oat plant height measured in July in terms of the different green manure and fertilization treatments**



Values with different letters are significantly different at the 95% confidence level by Tukey's test.

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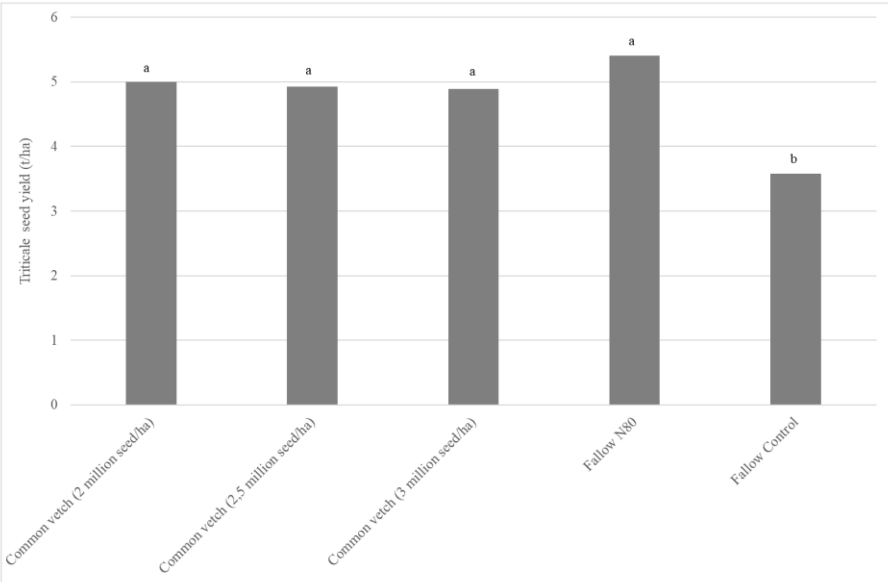
Effect of green manure on the yield of triticale, oat and corn

The positive effect of common vetch green manuring on the yield of the studied plants were significant for all three species. In the case of triticale, the yield of the control plots was 3.58 t ha^{-1} on average, in which the yield of green manured areas was 37.9% higher, with the average of 4.94 t ha^{-1}. The yield of the fertilized plots did not show a significant difference compared to the green manured plots, producing an average yield of 5.4 t ha^{-1} (*Figure 12*).

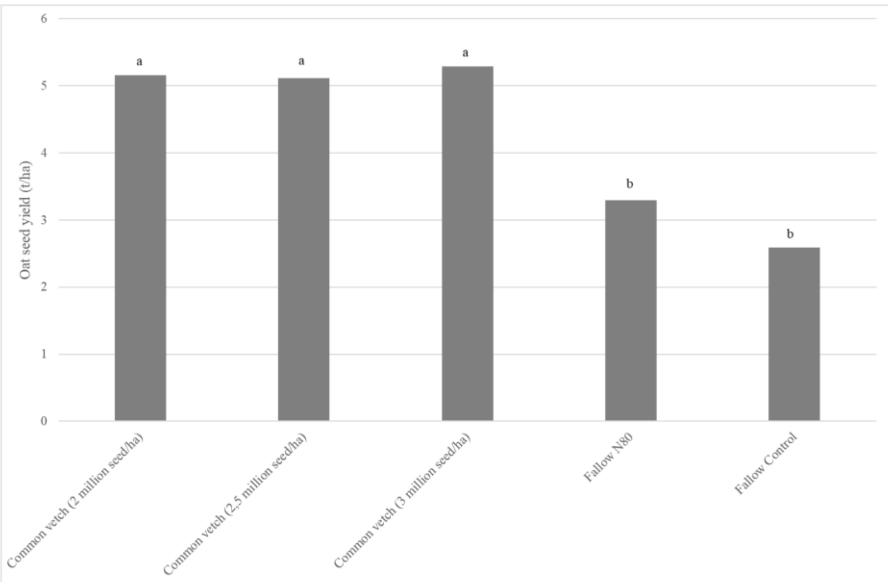
The positive reaction of oats to the common vetch green manure was also pronounced in terms of yields. There was no significant difference between the spring vetch green manuring with different seed densities, with an average yield of 5.18 t ha^{-1}. In contrast, the average yield of the control areas reached only 50% of the green manured areas, with the average of 2.59 t ha^{-1}. The yields of the fertilized areas are also lower than those of the green manured areas in case of oats (3.29 t ha^{-1}). According to Kramberger et al. (2009) and Justes et al. (2012), green manure plants provide an easily accessible source of N. Our results allow us to conclude that the nutrient forms bound by the common vetch and revealed during the decomposition of plant residues provides better availability for the oats plant than fertilizer applied as a top dressing in the spring (*Figure 13*).

Figure 12: **Triticale yields as a result of green manuring with different seed doses and fertilization treatments**



Values with different letters are significantly different at the 95% confidence level by Tukey's test.

Figure 13: **Oat yields as a result of green manuring with different seed doses and fertilization treatments**



Values with different letters are significantly different at the 95% confidence level by Tukey's test.

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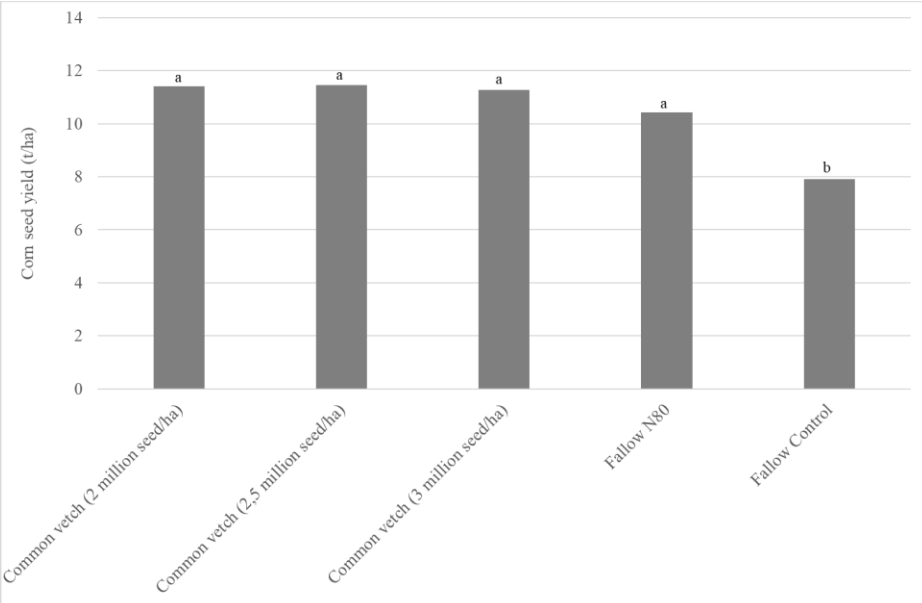
In our experiment, we not only showed the yield-increasing effect of common vetch in the case of cereals, we also achieved a statistically higher yield of corn compared to the control, and an effect equivalent to the results of the fertilized areas was observed in case of green manuring. In the case of plots green manured with common vetch, we harvested an average corn yield of 11.37 t ha^{-1}, which represents a 44% increase in yield compared to the control result of 7.91 t ha^{-1} (*Figure 14*).

Figure 14: **Corn yields as a result of green manuring with different seed doses and fertilization treatments**



Values with different letters are significantly different at the 95% confidence level by Tukey's test.

CONCLUSIONS

In our experiment, we proved several beneficial effects of common vetch green manure in the studied crop year. The water storage capacity was a significant factor in the drought period of June and July. In the case of the soil of the green manured areas, significantly higher moisture contents were observed. Green manuring contributed to the yield increase of the following plants compared to the control by creating an optimal soil condition in addition to the nutrient supply. The increase in yield was 37.9% for triticale, 50% for oats and 44% for corn compared to the control treatment.

Based on our experience, if a sufficient amount of precipitation falls during the growing season of the green manure application, there is no difference in the green mass due to the different seed densities, the effects were not different for the subsequent crops either in case of plant height and yield, but the positive effects were equally pronounced. Green fertilization was clearly proved to be a better alternative to bare fallow, as many authors determined (Biederbeck, 1990; Wright, 1990; Campbell et al., 1991).

We found yields equivalent to fertilization in both spring crops – higher in the case of oat –, the long-term effect of green manuring in the soil for the next crop is indisputable. In corn, a similar finding was published by Bayer et al. (2000), Sainju and Sing (1997) suggesting that the yield-enhancing effect of common vetch in corn may be equivalent to 66–200 kg ha^{-1} of N fertilizer.

The insertion of common vetch green manuring into crop rotations could be a justified and well-founded alternative to sustainable nutrient replenishment methods, with particular regard to the large increase in fertilizer prices. It can be used to reduce the input needs of farming, reduce CO_2 footprint, diversify the cultivated plant species portfolio, contribute to the protection of soils and increase the organic matter content of soils.

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