Theses of Doctoral (PhD) Dissertation

THE IMPORTANCE OF THE HAIRY VETCH (*VICIA VILLOSA* ROTH) IN SUSTAINABLE SAND MANAGEMENT

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1. INTRODUCTION

Today's arable crop production, in all aspects of agrotechnology, is very different from the industrial farming of the recent past. The soil degradation caused by industrial production has reached such a level that it is clear that arable farming based on this type of production cannot be sustained in the long term and is therefore unsustainable. Soil compaction, a decrease in organic matter content and pH, and severe soil life losses have all led to the need for sustainable land use.

The relatively limited range of crops that can be grown on acidic sandy soils, combined with the steady decline in available manure, has increased the value of green manuring on these soils, a practice that was almost forgotten during the industrialised period of arable farming. The most valuable green manure plants are the leguminous plants, which not only provided a significant amount of organic matter to the soil, but also enriched the upper layer of the soil with nitrogen via the symbiotic *Rhizobium* bacteria living on their roots.

Among the green manure plants that can be grown in the acidic sandy soils of the Nyírség, the hairy vetch occupies a prominent place because it can be grown successfully even under increasingly extreme weather conditions. Due to its special species characteristics, it tolerates dry soils with low precipitation in autumn, has excellent winter hardiness, regenerates quickly under favorable early spring weather conditions, and is capable of high biomass production. Our country's continental climate also allows for safe seed harvesting and the production of high-quality seeds. Its ability to suppress weeds and resist disease allows it to be used in organic crop nutrition and crop rotation. Even through its excellent agronomic value, the area under vetch has been small, even in organic farmers' fields, despite the fact that the best variety in Europe is still Hungvillosa, produced in Kisvárda, whose seed export has an unlimited market potential. The modest area under cultivation can be increased by changing farmers' mindsets, improving their knowledge of the crop, and refining cultivation techniques. In order to give this plant a proper place for its biological value in the sustainable use of the Nyírség sandy soils, it is essential to have a good understanding of its impact on the soil, its feeding value, and seed production, and to develop its cultivation technology more carefully than before.

1.1. Objectives of the dissertation

In the environmentally friendly utilization of the acidic sandy soils of the Nyírség, those leguminous cultivated plants are of great importance, whose species characteristics and agronomic values allow their integration into sandy soil management. They are essential for the technological elements of sustainable soil use, biological soil protection, and organic plant nutrition.

For the research I conducted for my dissertation, I formulated the following objectives:

- The effect of sowing date on the morphological parameters of hairy vetch and triticale in a breeding container experiment with pure and mixed sowing.
- Study of the growth dynamics of *Rhizobium* nodules on the roots of hairy vetch in a culture pot experiment in pure and mixed sowing.
- Effect of sowing date on generative yield traits (pod number, ear number, seed number, seed weight, and thousand kernel weight) of hairy vetch and triticale in a pure and mixed sowing in a culture pot experiment.
- Determination of the total yield and seed proportions (triticale, hairy vetch) of seed-bearing vetches sown in different cropping methods (mixed, band sown) in large-scale production.
- Investigation of the nitrogen content of seed-bearing hairy vetch grown in mixed cropping.

2. MATERIAL AND METHOD

2.1. The pilot sites

Our research has focused on field and laboratory studies. Our experiments were set up in the University of Nyíregyháza's Demonstration Garden in open field in breeding containers and in the University of Nyíregyháza's Educational Farm (Nyírtelek Ferenctanya) fields in large and small plots. In the laboratory, the morphological and nutritional data of the collected plant samples were recorded, and the physical, chemical, and biological characteristics of the soil samples were analysed.

2.1.1 The open field breeding container experiment

The measurements of our open field breeding container experiment were carried out in two growing years, at three sowing dates, with two sowing methods (pure and mixed) (Table 1). Our tests were aimed at investigating the morphological parameters of hairy vetch and triticale. The number of plants included in the experiment was 10.

Table 1: Presentation of the data from the open field breeding container experiment

Years examined	2019-2020	2020-2021
Sowing dates	20/09/2019 10/10/2019 10/30/2019	20/09/2020 10/10/2020 10/30/2020
Sowing methods	hairy vetch (20 seeds) mixed (26 pieces of triticale, 13 pieces of hairy vetch) triticale (62 seeds)	
Number of repetitions	6 containers/sowing dates//sowing method	
Observation dates	28/11/2019 23/04/2020 30/06/2020	8/12/2020 6/05/2021 9/07/2021
Parameters tested (morphological parameters, crop element tests)	at hairy vetch : plant height (cm) root length (cm) number of *Rhizobium* nodules, on the main root and lateral roots (pc) number of pods (pc)/plant number of seeds (pc)/pod seed weight (g) thousand kernel weight (g)	at triticale: plant height (cm) root length (cm) number of ears/plant (pc) number of seeds/ear (pc) seed weight (g) thousand kernel weight (g)
Soil sampling, from the pots of the first sowing date (20 Sep) 3x3x1 samples for soil analysis	28/11/2019 23/04/2020 30/06/ 2020	8/12/2020 6/05/ 2021 9/07/2021

Source: own table

2.1.2 The large plot field experiment

In our large plot field experiment (Table 2), we studied 4 years with two sowing methods (mixed and band sown). The total harvested yield of mixed and band sowing was determined. The yield is composed of two components (hairy vetch and triticale), so we also performed a seed ratio test in our measurements.

Table 2: Presentation of data from the large plot field experiment

Years examined	2017-2018.	2018-2019.	2019-2020.	2020-2021.
Area (ha)	13	12	12	12
Forecrop	Jerusalem artichoke	facelia	lea-land	sunflower
Sowing date	end of September	end of September	end of September	end of November
Sowing methods	band (6+2 row) mixed triticale (control plot)			
Quantity of seeds	70 kg triticale + 30 kg hairy vetch			
Line spacing	12.5 cm			
Agrotechnics, Care of the crop, Pest control	not applied			
Harvest	July 9, 2018	July 17, 2019	August 3, 2020	July 29, 2021
Definition of total seed yield/ha	Harvesting 100 metres banded, mixed sowing, triticale 4 repetitions/sowing method			
Determination of the seed ratio	mixed/banded sowing/16 repetitions			

Source: own table

2.1.3 The small plot field experiment

In our small plot field experiment, we studied 3 years of mixed sowing and the control (triticale) plot (Table 3). Nitrogen content was measured in the roots, stems, and seeds of plant samples harvested on 1 m^2. Soil samples were also taken before sowing and at harvest. In both sowing methods, we started our analysis by processing the plant parts (mass measurement) and then assigning the nitrogen amounts measured in them. Then, from the soil sample data taken at a depth of 30 cm (initial and harvest nitrate and nitrite), we calculated the surplus of N that could be taken up by the soil at harvest. From this, we calculated the soil N uptake (kg/ha) of the control plot and the mixed sowing, from which we detected the nitrogen uptake of the seed-bearing vetch.

Table 3: Summarizing the experimental background of the small plot field experiment

Years examined	2017-2018.	2018-2019.	2019-2020.
Forecrop	Jerusalem artichoke	facelia	lea-land
Total area (ha)	13	12	12
Within that	1 m^2		
Number of repetitions	4 repetitions	8 repetitions (4 - 4 were included in the experiment)	
Sowing dates	end of September	end of September	end of September
Sowing methods	mixed triticale (control plot)		
Quantity of seeds	70 kg triticale + 30 kg hairy vetch		
Line spacing	12.5 cm		
Agrotechnics, Care of the crop, Pest control	not applied		
Parameters tested	<u>in mixed sowing</u> root mass (g) stem mass (g) hairy vetch seed weight (g) triticale seed weight (g)	<u>control plot</u> root mass (g) stem mass (g) triticale seed weight (g)	
Determination of total nitrogen	at harvest (root, stem, seed)		
Sampling of soil:-before sowing -at harvest	September 2017 Jun 28, 2018	September 2018 July 1, 2019	September 2019 July 1, 2020

Source: own table

2.2. Evaluation of experimental data

SPSS and Microsoft Excel 2016 (Microsoft Corporation, 2016) spreadsheet software were used to evaluate the data. For the analyses, we used the mathematical-statistical methodology, two-sample t-test for expected value, correlation and regression analysis, and statistical estimation. Our statistical calculations and results were compared at a significance level of $p<0.05$. In all cases, before the t-tests, we tested the distribution of the original data with normality tests. In all cases, our tests were performed on small samples. In the breeding container experiment, we used a 10-item sample, while in the field large plot experiment, we used a 12-item sample. In the latter case, the sample element is defined as the plant cover per 1m^2.

Correlation and regression analyses were used to explore stochastic relationships and causal links between quantitative variables. The closeness of the relationship was determined using a Pearson bivariate linear correlation coefficient, and the underlying relationship was explored using a linear regression line.

3. RESULTS

3.1 The results of the open field breeding container trial

For the vast majority of crops grown in the field, the ratio of vegetative to generative biomass is heavily influenced by sowing date. In our open field experiments, we present the results of pure (only hairy vetch) and mixed (hairy vetch and triticale) sowings in 2019–2020 and 2020–2021, at 3 sowing dates.

3.1.1 The results of the vegetative biomass yield of pure sown hairy vetch

In our open field breeding container experiments, we used an independent sample t-test to compare the measured parameters across two sowing years (2019-2020, 2020-2021), three phenophases (pre-winter, bud formation stage, harvest), and three sowing dates (20 September, 10 October, 30 October). The first stage of our significance analysis was the comparison of the September 20 and October 10 sowing dates. In the second phase, we compared the measurements from 10 October to 30 October, and in the third phase, we compared the measurements from 20 September to 30 October. We separated these three stages because we considered it important both to detect changes in the process and to compare the trend between the extreme sowing dates (20 September and 30 October).

In both years studied, plant heights exceeded 10 cm at the earliest sowing date before the onset of winter (Table 4). In the October sowing dates, a decreasing trend in plant height was observed. Plant samples harvested at bud formation stage, measured in September, averaged between 30 and 47 cm. At the second sowing date, the values levelled off.
At the time of harvest, at the earliest sowing date, plant height was measured to be between 106-125 cm. Plant height at sowing on October 10 was below the values measured in September. An outlier was recorded in the 2019–2020 sowing year, where plant height was close to 140 cm. The two-sample t-test results for the expected value showed dominantly significant differences, demonstrating that sowing date has a significant effect on plant height. The only exceptions were observed at the harvesting stage in the third phase of the 2019–2020 crop year and in the second and third phases of the 2020–2021 crop year.

Table 4: Effect of sowing time on the plant height (cm) of pure sown hairy vetch with P values

	Plant height (cm)					
Sowing date	Befor winter		Bud formation stage		Harvest	
	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year
September 20	18.1	10.9	46.9	30.3	125.0	106.5
October 10	10.9	6.0	23.3	23.4	98.1	98.6
October 30	4.4	3.5	16.2	19.9	137.7	96.9
	P values					
September 20 - October 10	0.0002	0.0005	0.0000	0.0331	0.0420	0.1331
October 10 - October 30	0.0002	0.0000	0.0076	0.1191	0.0069	0.6247
September 20 - October 30	0.0000	0.0000	0.0000	0.0013	0.2778	0.0569

The average values of root lengths of the hairy vetch are presented in Table 5. Before the onset of winter, at the September sowings, a well-established stand was tested, with root lengths ranging from 16 to 26 cm. From the data in the table, it is clear that the results of the measurement at bud formation stage were significantly higher than before winter. At the time of harvest, there was a significant decrease compared to the values at the time of budding. In both years studied, significant differences in mean root lengths were observed at all measurement dates in the pre-winter phenophase. At bud formation stage, statistically verifiable differences were observed throughout the 2019–2020 crop year, whereas no significant differences were detected in any of the 2020–2021 crop years. The values at harvest gave variable results, with only two significant results, in the first and third stages of the 2020–2021 seeding year.

Table 5: Effect of sowing time on the root length (cm) of pure sown hairy vetch with P values

	Root lenght (cm)					
Sowing date	Befor winter		Bud formation stage		Harvest	
	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year
September 20	16.3	25.7	43.4	33.0	29.3	26.0
October 10	12.6	18.2	25.3	36.4	34.7	20.7
October 30	11.1	7.9	20.1	30.3	30.7	19.2
	P values					
September 20 - October 10	0.0207	0.0073	0.0000	0.3882	0.1449	0.0418
October 10 - October 30	0.3425	0.0002	0.0018	0.0785	0.3633	0.1778
September 20 - October 30	0.0091	0.0000	0.0000	0.2965	0.7348	0.0105

Tables 6-7 illustrate the evolution of the number of *Rhizobium* nodules on the main and secondary roots. The number of *Rhizobium* nodules on both main and secondary roots before winter showed a clear correlation with sowing date. The earlier the plants were sown, the higher the number of nodules on the roots. In early sowing, the appearance of Rhizobuim nodules ensures the late autumn establishment of above-ground biomass, which is the most important guarantee of soil cover for overwintering plants. The *Rhizobium* bacteria in the nitrogen nodules provide a constant supply of available nitrogen ions to the young plants, regardless of the amount of fossilised organic matter in the soil. The dynamics of nitrogen nodule development slow down from the beginning to the harvest phenophase, which explains why stands with different sowing dates level off. At bud formation stage, the difference between the sowing dates was no longer significant in all cases. By the time of harvest, most of the *Rhizobium* nodules had disappeared, so that the measurable differences disappeared.

Table 6: Development of the number of *Rhizobium* nodules, on the main root of pure sown vetch, P values

	Number of *Rhizobium* nodules on main root (pc)					
Sowing date	Before winter		Bud formation stage		Harvest	
	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year
September 20	9.4	11.5	6.8	6.8	0.0	0.0
October 10	7.6	5.9	7.8	5.6	0.0	0.0
October 30	4.7	0.4	3.4	5.8	0.0	0.0
	P values					
September 20 - October 10	0.2970	0.0098	0.1321	0.2661	0.0000	0.0000
October 10 - October 30	0.0915	0.0002	0.0000	0.8825	0.0000	0.0000
September 20 - October 30	0.0067	0.0000	0.0000	0.4239	0.0000	0.0000

Table 7: Development of the number of *Rhizobium* nodules on lateral roots of pure sown vetch, P values

	Number of *Rhizobium* nodules on lateral root (pc)					
Sowing date	Before winter		Bud formation stage		Harvest	
	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year
September 20	9.6	7.6	27.6	13.7	2.0	2.8
October 10	6.3	0.8	9.6	13.5	0.6	0.4
October 30	0.0	0.0	11.9	11.7	7.6	1.7
	P values					
September 20 - October 10	0.2796	0.0002	0.0000	0.9558	0.1545	0.0699
October 10 - October 30	0.0208	0.0868	0.1145	0.5895	0.0156	0.1781
September 20 - October 30	0.0007	0.0000	0.0002	0.4106	0.0454	0.4590

3.1.2 The results of generative yields of pure sown hairy vetch

In Table 8, the data on number of pods and number of seeds in the pod are presented. As the sowing season progressed, pod numbers increased, with the exception of the mid-October sowing of the 2020–2021 sowing year. In both years studied, the number of pods harvested at the first and last sowing dates increased the number of pods per plant by nearly 4 per plant. The same trend can be observed for the number of seeds per plant, with the number of seeds on October 30 being more than 12 more than on September 20. For pod numbers and seed numbers, no significant difference between the mean values could be detected at the three sowing dates.

Table 8: Development of the number of pods and seeds per plant of pure sown vetch, P values

	Number of pods (pc)/plant		Number of seeds (pc)/plant	
Sowing date	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year
September 20	5.6	8.5	13.9	22.2
October 10	7.9	6.6	17.6	15.0
October 30	9.5	12.2	27.7	34.6
	P values		P values	
September 20 - October 10	0.2528	0.4356	0.3721	0.2313
October 10 - October 30	0.5036	0.0143	0.1091	0.0073
September 20 - October 30	0.0283	0.0860	0.0168	0.0937

The evolution of seed weight and thousand kernel weight is summarised in Table 9. For seed weight and thousand kernel weight, the latest sowing date showed a significant difference in both years studied.

Table 9: Development of seed weight and thousand kernel weight of pure sown hairy vetch (pieces), P values

	Seed weight (g)/plant		Thousand kernel weight (g)	
Sowing date	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year
September 20	0.25	0.39	18.29	17.63
October 10	0.40	0.37	22.18	24.29
October 30	0.57	0.79	21.77	23.32
	P values		P values	
September 20 - October 10	0.1520	0.8699	0.0173	0.0000
October 10 - October 30	0.1833	0.0079	0.8134	0.4118
September 20 - October 30	0.0028	0.0081	0.0133	0.0000

3.1.3 The results on the vegetative biomass yield of mixed sown hairy vetch

The plant height of hairy vetch showed a decreasing trend as the sowing dates progressed (Table 10). An intense decrease in plant height was observed during the pre-winter phenophase in the 2019-2020 sowing year, with a decrease of more than 12 cm between the first and last sowing dates. The intensity of the decrease was lower during the bud formation stage. The most intense plant height decrease was measured at harvest, when there was a height difference of nearly 30 cm between the first and last sowing date plants. In both years studied, the 10 October measurement result data set shows a high value at the phenophase of harvest, probably due to weather conditions. Comparing the different measurement dates, the difference in plant heights was significant in most cases in all three phenophases. The most significant difference in results was observed in the pre-winter phenophase.

Table 10: Effect of sowing time on plant height (cm) of mixed sown hairy vetch, P values

	Plant height (cm)					
Sowing date	Befor winter		Bud formation stage		Harvest	
	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year
September 20	16.9	10.7	29.8	29.0	127.0	90.3
October 10	10.6	5.9	24.9	27.4	132.8	105.9
October 30	4.2	3.4	18.3	25.0	97.2	64.0
	P values					
September 20 - October 10	0.0000	0.0000	0.0915	0.4280	0.6315	0.0233
October 10 - October 30	0.0000	0.0000	0.0024	0.2182	0.0006	0.0000
September 20 - October 30	0.0000	0.0000	0.0004	0.0455	0.0336	0.0009

According to the data in Table 11, the root lengths of mixed-sown vetch show, in most cases, a decreasing trend as the sowing period progresses. In both years studied, an intense decline was measured before the onset of winter, similar to the plant height. An intense decrease in plant height can be observed at bud formation stage in 2019–2020 and at harvest in 2020–2021. The significance results for the differences in root lengths at each measurement date show a much more varied picture than for plant height. In 9 of the 18 comparisons, we found that there was a significant difference between root lengths measured at successive sowing dates, while in the other half, we could not statistically confirm this.

Table 11: Effect of sowing time on root length (cm) of mixed sown hairy vetch, P values

Sowing date	Root lenght (cm)					
	Befor winter		Bud formation stage		Harvest	
	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year
September 20	15.8	20.7	29.4	25.0	33.1	29.3
October 10	12.4	16.6	24.9	27.7	31.4	23.0
October 30	6.5	7.7	18.1	22.1	33.9	16.9
	P values					
September 20 - October 10	0.1404	0.0857	0.0488	0.1234	0.5703	0.0171
October 10 - October 30	0.0010	0.0006	0.0000	0.0141	0.4872	0.0076
September 20 - October 30	0.0006	0.0000	0.0001	0.2066	0.7284	0.0000

The data in Tables 12–13 were used to investigate the number of *Rhizobium* nodules on the main and lateral roots of mixed-sown hairy vetch. In all cases, the number of *Rhizobium* nodules on the main root decreased as the sowing period progressed, so that in most cases, a significant difference was detected by t-tests. In the 2019-2020 and 2020-2021 growing years, no *Rhizobium* nodules were found on the main root at harvest phenophase, so no statistical evaluation was performed.

Table 12: Trends in the number of *Rhizobium* nodules on the main root of mixed sown vetch, P values

Sowing date	Number of *Rhizobium* nodules on main root (pc)					
	Before winter		Bud formation stage		Harvest	
	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year
September 20	7.7	8.4	6.7	5.4	0	0
October 10	7.3	5.7	5.6	3.2	0	0
October 30	3.6	0.0	1.7	2.9	0	0
	P values					
September 20 - October 10	0.8606	0.0686	0.0838	0.0094	-	-
October 10 - October 30	0.0239	0.0000	0.0000	0.5569	-	-
September 20 - October 30	0.0550	0.0000	0.0000	0.0031	-	-

In almost all cases, as the sowing date shifted, the number of *Rhizobium* nodules on the lateral roots decreased (Table 13). The average number of nodules formed on the lateral roots was below 10 in the plants studied. Higher numbers of nodules were measured in all three phenophases in the 2019-2020 year.

Table 13: Development of the number of *Rhizobium* nodules on lateral roots of mixed sown vetch, P values

	Number of *Rhizobium* nodules on lateral root (pc)					
Sowing date	Before winter		Bud formation stage		Harvest	
	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year
September 20	9.3	4.2	8.4	6.3	1.7	0
October 10	2.0	0.7	8.1	3.2	0.5	0
October 30	0.0	0.0	4.9	1.7	2.5	0
	P values					
September 20 - October 10	0.0119	0.0064	0.7805	0.0122	0.0088	-
October 10 - October 30	0.1226	0.0885	0.0000	0.1056	0.0010	-
September 20 - October 30	0.0025	0.0019	0.0063	0.0016	0.1594	-

3.1.4 The results of generative yields of mixed sown hairy vetch

Tables 14 to 15 show the yield components of the hairy vetch. In the years studied, both the number of pods and the number of seeds show an increasing trend as the sowing period progresses. In both years studied, the number of pods more than doubled. A significant increase in the number of seeds was observed as the sowing period progressed.

Table 14: Development of number of pods and number of seeds per plant in mixed sown vetch, P values

	Number of pods (pc)/plant		Number of seeds (pc)/plant	
Sowing date	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year
September 20	7.1	9.2	22.5	28.1
October 10	10.5	17.6	27.7	39.7
October 30	17.7	21.4	37.8	44.5
	P values		P values	
September 20 - October 10	0.0001	0.0002	0.0271	0.0444
October 10 - October 30	0.0002	0.0317	0.0043	0.3150
September 20 - October 30	0.0000	0.0000	0.0001	0.0010

The sowing date also affects the results for seed weight and thousand kernel weight (Table 15), as they show an increasing trend in both years. In the case of seed weight, there is a significant quantitative difference between crops sown on September 20 and those sown on October 30. For seed weight, significant differences were measured in most cases. For thousand kernel weight only a slight increase was observed. For sowings on September 20, the thousand kernel weight is less than 20 grams. Although there is an increase with the shift in sowing date, this increase is only a few percent at the latest sowing date. As regards the weight per thousand seeds, the differences are not statistically verifiable in most cases.

Table 15: Development of seed weight and thousand kernel weight (pieces) of mixed sown vetch, P values

	Seed weight (g)/plant		Thousand kernel weight (g)	
Sowing date	2019-2020 sowing year	2020-2021 sowing year	2019-2020 sowing year	2020-2021 sowing year
September 20	0.44	0.56	19.66	19.95
October 10	0.56	0.82	20.33	20.71
October 30	0.77	0.95	20.53	21.33
	P values		P values	
September 20 - October 10	0.0134	0.0247	0.3586	0.2527
October 10 - October 30	0.0053	0.1450	0.8129	0.1368
September 20 - October 30	0.0001	0.0002	0.3631	0.0392

3.2 The results of the large plot field experiment

In our large plot field experiment, the total harvested yield of the four years under study was measured in 4 replicates, using different sowing methods (mixed, band sown). Our further investigations will also include the seed rate of the sowing mode. Since two plant components are present in the seed lot (hairy vetch and triticale), it was considered important to detect their proportions.

The data in Table 16 show that the average deviation from the mean is relatively large for both the mixed (534 kg) and the band (610 kg) sowings. However, the relative standard deviation value suggests that the distribution of the measurement results is still homogeneous. From the average data of the years under investigation, it is clear that in the average of the 4 repetitions, band sowing gave a higher total yield per hectare. The highest yields in our experiments were obtained in the 2017-2018 season, with an average of 2553 kg/ha in mixed sowing and 3133 kg/ha in band sowing, averaged over four replications. During the evaluation of the data, the 2020–2021 cultivation year can be highlighted. That year, the crop volumes were good, we harvested nearly 2,000 kg in mixed sowing and more than 2,300 kg in band sowing per hectare. In these years, the meteorological data clearly supported the fact that both temperature and precipitation data developed favorably. The temperature data in the autumn and spring months also exceeded the long-term average, by more than 1.8 °C on an annual basis. Of the four years examined, the two rainiest were the 2017–2018 and 2020–2021 growing years, where the amount of precipitation exceeded the long-term average by more than 60 mm. The distribution of precipitation was also relatively even.

Table 16: Total harvested quantities for the years under examination (triticale and hairy vetch) per plot in 4 replicates

Years examined	Parcel/repeat number	Mixed sowing	Band sowing
		Total harvested crop (kg/ha)	Total harvested crop (kg/ha)
2017-2018.	I./1.	2358	2932
	I./2.	2474	3036
	I./3.	2632	3194
	I./4.	2748	3370
	Average	2553	3133
2018-2019.	II./1	1167	1750
	II./2.	1250	1084
	II./3.	1917	1916
	II./4.	1334	2334
	Average	1417	1771
2019-2020.	III./1.	1250	1750
	III./2.	1300	2050
	III./3.	1350	2216
	III./4.	1200	1584
	Average	1275	1900
2020-2021.	IV./1.	2016	2518
	IV./2.	1856	2123
	IV./3.	2123	2028
	IV./4.	1749	2615
	Average	1936	2321
Average		1795.25	2281.25
Average deviation		534	610
Relative standard deviation		30%	27%

In Table 17, the total harvested yields of the years under study for mixed and banded sowing and the seed rates of triticale and hairy vetch are shown. In mixed sowings, the average percentage of triticale was 72.7%, while the percentage of hairy vetch was 27.3%. The average seed rate of triticale grown in the band sowing system is more than 11% higher than in the mixed-sowing system. In this sowing method, the seed rate of hairy vetch is less than 20%. The average seed yield per hectare of triticale in mixed sowing is 1300 kg, while that of hairy vetch is close to 500 kg. A higher average triticale seed yield per hectare was recorded in band sowing, nearly 1850 kg, but the seed yield of the hairy vetch was lower by more than 50 kg.

In mixed sowings, the average triticale content of the years studied varied between 61–83%, while the seed content of the hairy vetch varied between 17–39%. The proportion of triticale in band sowings was higher than in mixed sowings (75–87%), but the proportion of seeds in the case of hairy vetch was lower (13–25%).

Table 17: Average of total yields for the years studied, seed rate averages, mixed and banded sowings

Mixed sowing					
Years examined	Total harvested crop (kg/ha)	Triticale seed proportion (%)	Hairy vetch seed proportion (%)	Triticale (kg/ha)	Hairy vetch (kg/ha)
	2553	78.5	21.5	2004	549
2018-2019.	1417	82.9	17.1	1175	242
2019-2020.	1275	67.5	32.5	861	414
2020-2021.	1936	61.7	38.3	1195	741
Average	1795	72.7	27.3	1308.8	486.5
Band sowing					
Years examined	Total harvested crop (kg/ha)	Triticale seed proportion (%)	Hairy vetch seed proportion (%)	Triticale (kg/ha)	Hairy vetch (kg/ha)
	3133	83.5	16.5	2616	517
2018-2019.	1771	86.2	13.8	1527	244
2019-2020.	1900	78.7	21.3	1495	405
2020-2021.	2321	75.7	24.3	1757	564
Average	2281.3	81	19	1848.8	432.5

3.3 The results of small plot field experiment

The field trials were conducted in small plot experiments to study the nitrogen uptake of mixed-sown seed-bearing vetch. In both sowing methods, we started our study by processing the plant parts (mass measurement) and then assigning the measured nitrogen amounts to them. Then, from the soil sample data (initial and harvest nitrate and nitrite) taken from a depth of 30 cm, we calculated the surplus of N that could be taken up by the soil at harvest. From this, we calculated the soil N uptake (kg/ha) of the control plot and the mixed sowing, showing the nitrogen uptake of the seed-bearing vetch.

3.3.1 Determination of the nitrogen content of the seed samples of control and mixed crop

In the following tables (18–19), we present the root mass, straw mass, and seed mass measured in the 1 m^2 control plot and in the mixed sowing, their nitrogen contents, and the results of the pairwise correlation relationships.

Based on the test results of the control plot (Table 18), a weak correlation was observed between root mass or straw mass and their nitrogen content. The average root mass was 0.28 kg/m2 and its nitrogen content was 0.38%, while the average straw mass was 0.25 kg/m2 and its nitrogen content was 0.40%. The average triticale grain weight per square meter was found to be 0.18 kg, while the average triticale grain nitrogen content was 1.76%. The results of the measurements show homogeneity for both triticale grain weight and triticale seed nitrogen content. For the former, the relative standard deviation is 26%; for the latter, it is only 8%. Among the results from the control plot, a strong negative correlation (r = -0.69) was found between triticale grain volume and triticale grain nitrogen content. This means that if the amount of triticale seed per 1 m^2 increases, its nitrogen content is expected to decrease.

Table 18: Weight of plant parts harvested per 1 m^2 and their N content measured in the control plot in 4 replicates in the years studied

Years examined/ sowing method//repeat number	Root mass kg/m^2	N content of the root (%)	Straw mass kg/m2	N content of the stem (%)	Triticale seeds kg/m^2	N content of triticale seeds (%)
2017-2018. Control 1	0.32	0.49	0.24	0.41	0.20	1.66
2017-2018. Control 2	0.26	0.34	0.28	0.32	0.20	1.85
2017-2018. Control 3	0.26	0.41	0.20	0.36	0.25	1.77
2017-2018. Control 4	0.26	0.35	0.27	0.30	0.20	1.69
2018-2019. Control 1	0.24	0.33	0.19	0.48	0.20	1.57
2018-2019. Control 2	0.21	0.37	0.19	0.48	0.18	1.85
2018-2019. Control 3	0.26	0.37	0.24	0.40	0.28	1.43
2018-2019. Control 4	0.18	0.38	0.15	0.40	0.14	1.91
2019-2020. Control 1	0.30	0.37	0.28	0.44	0.13	1.88
2019-2020. Control 2	0.30	0.36	0.30	0.38	0.16	1.91
2019-2020. Control 3	0.46	0.40	0.40	0.39	0.13	1.75
2019-2020. Control 4	0.35	0.39	0.22	0.46	0.11	1.87
Average	**0.28**	**0.38**	**0.25**	**0.40**	**0.18**	**1.76**
Deviation	**0.07**	**0.04**	**0.06**	**0.05**	**0.05**	**0.14**
Relative standard deviation	**24%**	**10%**	**25%**	**14%**	**26%**	**8%**
r	**0.36**		**-0.32**		**-0.69**	

In the case of mixed sowing, the strongest correlation was observed for straw mass (Table 19), with a medium-strong negative relationship (r = -0.50) between straw mass and nitrogen content. An increase in stalk mass per 1 m^2 results in a decrease in nitrogen content. A weak positive correlation (r = 0.31) was observed between root mass and nitrogen content, suggesting that an increase in root mass per 1 m^2 is expected to increase the nitrogen content of the root. There is a very weak correlation between triticale seed and its nitrogen content (r = 0.06) and a weak correlation in the negative direction (r = -0.31) between the amount of hairy vetch seed and its nitrogen content. The latter suggests that if the mass per m^2 of vetch seed increases, the nitrogen content of vetch seed is expected to decrease. As for the descriptive statistics, the average straw mass is 0.44 kg/m^2, the standard deviation is 0.14 kg/m^2, the average nitrogen content of the stalk is 0.58 %, the standard deviation is 0.09 %. For the below-ground and above-ground parts of the plant, a weak correlation between the plant part and the nitrogen content was observed.

Table 19: Weight of crop parts harvested per 1 m^2 and their N content in mixed sowings in 4 replicates in the years studied

Years examined/ sowing method//repeat number	Root mass kg/m2 ő	N content of the root (%)	Straw mass kg/m2	N content of the stem (%)	Triticale seeds kg/m^2	N content of triticale seeds (%)	Hairy vetch seeds kg/m^2	N content of hairy vetch seed (%)
2017-2018. Mixed 1	0.36	0.61	0.62	0.51	0.20	2.37	0.06	4.62
2017-2018. Mixed 2	0.43	0.45	0.57	0.51	0.23	2.32	0.05	4.64
2017-2018. Mixed 3	0.28	0.52	0.47	0.58	0.22	2.08	0.04	4.53
2017-2018. Mixed 4	0.32	0.47	0.51	0.43	0.16	2.39	0.04	4.36
2018-2019. Mixed 1	0.18	0.52	0.24	0.63	0.17	2.07	0.02	4.54
2018-2019. Mixed 2	0.22	0.47	0.28	0.66	0.21	2.25	0.03	4.71
2018-2019. Mixed 3	0.20	0.34	0.28	0.77	0.17	2.99	0.03	5.07
2018-2019. Mixed 4	0.24	0.45	0.27	0.61	0.14	1.98	0.02	4.69
2019-2020. Mixed 1	0.31	0.50	0.39	0.46	0.14	2.29	0.04	4.30
2019-2020. Mixed 2	0.43	0.51	0.40	0.65	0.08	1.92	0.06	4.08
2019-2020. Mixed 3	0.29	0.45	0.67	0.63	0.10	2.25	0.03	4.40
2019-2020. Mixed 4	0.39	0.48	0.54	0.57	0.05	2.50	0.04	4.69
Average	**0.30**	**0.48**	**0.44**	**0.58**	**0.16**	**2.28**	**0.04**	**4.55**
Deviation	**0.08**	**0.06**	**0.14**	**0.09**	**0.05**	**0.27**	**0.01**	**0.24**
Relative standard deviation	**27%**	**12%**	**33%**	**16%**	**35%**	**12%**	**28%**	**5%**
r	**0.31**		**-0.50**		**0.06**		**-0.31**	

The data in Tables 18–19 were used to calculate the N content per ha in roots, stems, and seeds (the weight of plant parts was multiplied by the N content per ha and then expressed per ha).
The nitrogen content values of the control plot are presented in Table 20. On average, the highest nitrogen content was measured in the triticale seed (31.53 kg/ha), with only a third of this amount in the root and stem.
Table 20 summarizes the nitrogen amounts measured in the mixed sowing, as well as the control plot values.
The lowest nitrogen content was measured in the root (14.81 kg/ha), a few % more nitrogen was measured in the hairy vetch seed (17.42 kg/ha), followed by the nitrogen content in the stem (24.85 kg/ha), and the peak of nitrogen accumulation was concentrated in the triticale seed (35.69 kg/ha). In all cases, the average nitrogen content measured in the control plot was higher than the results of the mixed sowing. There was a difference of almost one and a half times in

the nitrogen content of the root, two and a half times for the stem, and 13 % for the triticale seed.

Table 20: Nitrogen amounts (kg/ha) measured in control plot and mixed sowing, in 4 replicates in the years studied

Years examined/ sowing method//repeat number	N content of the root kg/ha	N content of the stem kg/ha	N content of triticale seed kg/ha	Years examined/ sowing method//repeat number	N content of the root kg/ha	N content of the stem kg/ha	N content of triticale seed kg/ha	N content of hairy vetch seed kg/ha
2017-2018. Control 1	15.59	9.81	33.28	2017-2018. Mixed 1	21.78	31.54	47.31	27.71
2017-2018. Control 2	8.89	8.90	37.06	2017-2018. Mixed 2	19.29	29.16	53.44	21.03
2017-2018. Control 3	10.58	7.13	44.25	2017-2018. Mixed 3	14.51	27.43	45.68	18.11
2017-2018. Control 4	9.15	8.13	33.89	2017-2018. Mixed 4	15.16	21.68	38.16	15.27
2018-2019. Control 1	7.89	9.23	30.78	2018-2019. Mixed 1	9.49	15.16	35.22	10.50
2018-2019. Control 2	7.72	9.26	34.07	2018-2019. Mixed 2	10.25	18.40	47.72	15.17
2018-2019. Control 3	9.65	9.67	39.27	2018-2019. Mixed 3	6.88	21.23	51.66	17.02
2018-2019. Control 4	7.04	5.90	27.47	2018-2019. Mixed 4	10.80	16.28	27.68	11.21
2019-2020. Control 1	11.06	12.32	24.50	2019-2020. Mixed 1	15.84	17.98	31.43	16.33
2019-2020. Control 2	10.80	11.40	30.52	2019-2020. Mixed 2	21.91	26.12	15.90	22.86
2019-2020. Control 3	18.32	15.60	22.78	2019-2020. Mixed 3	13.03	42.28	21.81	14.52
2019-2020. Control 4	13.65	10.12	20.53	2019-2020. Mixed 4	18.79	30.88	12.24	19.25
Average	**10.86**	**9.79**	**31.53**	**Average**	**14.81**	**24.85**	**35.69**	**17.42**

3.3.2 Determination of the available nitrogen content of soil samples

Based on the soil test data, we reviewed the nitrate and nitrite (mg/kg) of soil sampled at a depth of 30 cm per 1 m2 in both the control and the mixed sowing (Table 21). Examining the nitrate and nitrite content (mg/kg) of the control plot soil, it was found that the average of the values measured before sowing was 7.68 mg/kg. At harvest phenophase, there was a slight increase in all years studied, for the 12 replicates, to an average of 9.8 mg/kg. The difference between the two averages is 2.12 mg/kg of soil N uptake surplus at harvest.

In mixed sowings, the average nitrate and nitrite content at baseline (before sowing) was 9.75 mg/kg. At the harvest phenophase, an increase of more than 62 % was measured, with the average value increasing to 15.83. Thus, the soil N surplus was 6.08 mg/kg.

When comparing the nitrate and nitrite (mg/kg) results in the soil from the control plot and the mixed sowing, both at baseline and at harvest, it can be concluded that the values measured in the mixed sowing show higher results. A two-sample t-test was used to test the difference between the initial (measured before sowing) and the average nitrate and nitrite content at harvest in the control plot and in the mixed plot. In the control plot, there was no significant difference in the mean nitrate and nitrite content between the initial and harvested plots ($P = 0.0808$). In contrast, in the mixed plot, there was a significant difference between these values

(P = 0.0000). This suggests that the nitrogen-enhancing effect of seed-bearing vetch is not due to chance.

Table 21: Detection of the active N content in the form of nitrite+nitrate in the soil measured per 1m^2 and the excess of N that can be absorbed by the soil in the control plot and in the mixed sowing plot in 4 replicates in the years studied

Years examined/ sowing method//repeat number	Control			Years examined/ sowing method//repeat number	Mixed sowing		
	Nitrate and nitrite (mg/kg)		Excess N available to the soil at harvest (mg/kg)		Nitrate and nitrite (mg/kg)		Excess N available to the soil at harvest (mg/kg)
	Baseline	Harvest			Baseline	Harvest	
2017-2018. Control 1	5.38	7.42	2.04	2017-2018. Mixed 1	5.71	10.88	5.17
2017-2018. Control 2	4.04	5.64	1.6	2017-2018. Mixed 2	6.08	12.25	6.17
2017-2018. Control 3	6.03	7.67	1.64	2017-2018. Mixed 3	7.17	12.43	5.26
2017-2018. Control 4	3.18	4.79	1.61	2017-2018. Mixed 4	7.72	13.26	5.54
2018-2019. Control 1	8.35	10.68	2.33	2018-2019. Mixed 1	11.95	18.55	6.6
2018-2019. Control 2	7.38	9.97	2.59	2018-2019. Mixed 2	14.26	20.95	6.69
2018-2019. Control 3	8.42	12.10	3.68	2018-2019. Mixed 3	11.14	17.76	6.62
2018-2019. Control 4	12.1	14.80	2.7	2018-2019. Mixed 4	10.96	16.27	5.31
2019-2020. Control 1	11.13	12.34	1.21	2019-2020. Mixed 1	10.77	16.14	5.37
2019-2020. Control 2	8.61	10.12	1.51	2019-2020. Mixed 2	10.46	17.62	7.16
2019-2020. Control 3	7.23	9.91	2.68	2019-2020. Mixed 3	9.67	16.82	7.15
2019-2020. Control 4	10.28	12.18	1.9	2019-2020. Mixed 4	11.15	17.02	5.87
Average	**7.68**	**9.80**	**2.12**	**Average**	**9.75**	**15.83**	**6.08**

Nitrate and nitrite (mg/kg) results measured in the soil in the control and mixed sowing methods were used to determine the nitrogen uptake rates. These values provide the fundamental information required to calculate the amount of nitrogen that the soil can absorb. Our calculations were based on the difference between the harvested and baseline nitrate and nitrite (mg/kg) content of the soil. The air dry mass of the upper 30 cm layer of 1 m^2 of soil was determined and used to analyze the soil's upper 30 cm layer. After drying our soils, we obtained an average value of 1.4 kg/dm^3. As a result, we used 420 kg of soil per 1 m^2 in our subsequent calculations.

In Table 22, the nitrogen uptake of soil from 1 m^2 plots taken from a depth of 30 cm (420 kg soil) is presented for 1 ha. Based on the averages of the measured results, the nitrogen uptake in the soil of the control plot was 8.92 kg/ha, while in the case of the mixed sowing it was 25.52 kg/ha. The amount of nitrogen uptake measured in the soil of the mixed plot is almost three times higher than in the control plot. This difference is statistically supported by a t-test (P = 0.0000). The difference in the amount of nitrogen that can be taken up by the mixed and control plots is 16.6 kg.

Table 22: Identification of variations and increases in N uptake (kg/ha) in the mixed sowing plot and the control plot

Years examined/ sowing method//repeat number	The available quantity of N kg/ha	Sowing method//repeat number	The available quantity of N kg/ha	Difference in the available quantity of N (mixed-control) kg/ha
2017-2018. Control 1	8.57	2017-2018. Mixed 1	21.71	13.15
2017-2018. Control 2	6.72	2017-2018. Mixed 2	25.91	19.19
2017-2018. Control 3	6.89	2017-2018. Mixed 3	22.09	15.20
2017-2018. Control 4	6.76	2017-2018. Mixed 4	23.27	16.51
2018-2019. Control 1	9.79	2018-2019. Mixed 1	27.72	17.93
2018-2019. Control 2	10.88	2018-2019. Mixed 2	28.10	17.22
2018-2019. Control 3	15.46	2018-2019. Mixed 3	27.80	12.35
2018-2019. Control 4	11.34	2018-2019. Mixed 4	22.30	10.96
2019-2020. Control 1	5.08	2019-2020. Mixed 1	22.55	17.47
2019-2020. Control 2	6.34	2019-2020. Mixed 2	30.07	23.73
2019-2020. Control 3	11.26	2019-2020. Mixed 3	30.03	18.77
2019-2020. Control 4	7.98	2019-2020. Mixed 4	24.65	16.67
Average	**8.92**	**Average**	**25.52**	**16.60**

3.3.3 Nitrogen uptake by seed-bearing hairy vetch

The amounts of nitrogen (kg/ha) measured in roots, stems, and seeds are shown as averages for the various sowing methods in Table 23. The table's final column shows the amount of N (kg/ha) that can be absorbed from the soil. Higher N amounts were measured in mixed sowings, both in crop parts and in the soil, than in control sowings. The basic data for the calculation of the N collection was given by the difference between the N measured in the root, stem, seed, and soil of the mixed and control plots.

Based on the amounts of nitrogen measured in the roots (3.95 kg/ha), stems (15.06 kg/ha) and soil (16.33 kg/ha) of the seed-bearing vetch stand, the nitrogen surplus remaining in the soil is 35.34 kg/ha with an approximate precision.

Table 23: Average (kg/ha) and increment of N in roots, stems, seeds, and soil of the plants in the mixed sowing and control plots

Sowing method//repeat number	N content of the root kg/ha	N content of the stem kg/ha	N content of triticale seed kg/ha	N content of hairy vetch seeds kg/ha	The available quantity of N (from soil) kg/ha
Average of mixed sowir	14.81	24.85	35.69	17.42	25.25
Average of Control	10.86	9.79	31.53	-	8.92
Differences	**3.95**	**15.06**	**4.16**	**17.42**	**16.33**

4. NEW SCIENTIFIC RESULTS

1. The response of the hairy vetch to sowing date is excellent among the overwintering annuals, in both pure and mixed sowing, as the plant traits and characteristics measured clearly reflect trends in sowing date variation. Hairy vetch has a pure sowing date response in terms of vegetative yield formation. In the late September sowing season, the average height of the plants measured before the onset of winter was 11–18 cm, while the root length ranged from 16–26 cm. In the sowing season at the end of October, a decreasing trend was observed, with plant height ranging from 3.4 to 4.4 cm and root length from 6.5 to 11.1 cm. In this early sowing period, the use of hairy vetch as a green manure provides the best protection and nitrogen enrichment for the soil.
2. The dynamics of Rhizobium nodule formation are greatest in early sowings in both sowing methods (pure and mixed). Examining *Rhizobium* nodule counts on the main root, we found that in pure sown, pre-winter, and pre-budding hairy vetch sown at the end of September, more nodules were counted (6.8–11.5) than in mixed sown (5.4–8.4). In both sowing modes, by the phenophase of harvest, the nodules on the main root were absorbed. Rhizobium nodules on lateral roots at the pre-winter time points in the pure sowing were somewhat, but not much, higher than in the mixed sowing. When examining the number of nodules on the lateral root, significant differences were measured at the phenophase of budding in pure seed. In pure sowing, we counted 9.6–27.6 nodules, while in mixed sowing, we counted 1.7–8.4 nodules.
3. Sowing date has an effect on seed-bearing vetch production as well. The latest sowing date resulted in a significant difference in seed weight and in thousand kernel weight in pure sowing. As the sowing date increased, the kernel weight increased from an average of 17 g to 25 g in pure sowing and from an average of 19 g to 22 g in mixed sowing.
4. Sowing methods have an impact on total yield and seed rates. Yields were consistently higher for band sowing (2281 kg/ha) than for mixed sowing (1795 kg/ha) over the years studied. Band sowing resulted in higher yields. For increased yields, band sowing is preferable. The proportion of hairy vetch in the mixed sowing was much higher than in the band sowing in terms of seed ratios. In mixed sowings, the average seed rate for triticale was 72.7% and 27.3% for vetch. The average seed rate of triticale grown by banded sowing is more than 11% higher than that of mixed sowing. In this sowing method, the seed rate of hairy vetch is less than 20%. For the production of hairy vetch for seed production and sale, the mixed sowing method is recommended.

5. The mixed cropping of seed-bearing vetch enriches the soil with nitrogen. In terms of preplant effect, based on the root, stalk and soil nitrogen levels of seed-bearing hairy vetch, 35.34 kg/ha of excess nitrogen is left in the soil for the follow-on crop.

5. RESULTS THAT CAN BE APPLIED IN PRACTICE

1. Early sowing (pure and mixed) results in a visible crop on the soil surface before winter sets in. When grown for green manure, vetch is the most soil-protective crop at this sowing date. The formation of vegetative biomass (green mass) is also at its peak during this sowing period, which is important for the production of mixed green fodder. At later sowing dates, the green and root mass produced until harvest is significantly reduced. Root length at harvest is significantly shorter than pre-winter and budding values. The decomposition of the root system and the onset of mineralisation of the maturing hairy vetch lead to root sucking. For the production of green manure and green fodder, sowing in September is recommended.
2. The late sowing date has an effect on the yield of seed-bearing hairy vetch. Late-sown vetch, after rapid development in spring, produces a generative stand type with higher pod number, seed number, seed weight, and thousand kernel weight compared to early-sown plants. And for a safe seed set, a sowing date in late October is recommended.
3. Sowing methods influence the total yield and the seed rates. Yields, averaged over the years studied, exceeded in all cases the total yields harvested from the mixed sowing in the case of band sowing. Sowing in bands can result in higher yields. Banding is preferable for increased yields. The proportion of hairy vetch in the mixed sowing was much higher than in the band sowing in terms of seed ratios. The mixed sowing method is recommended for hairy vetch cultivation for seed cultivation and sale.
4. The favourable pre-sowing value of vetch has been confirmed, as in addition to its beneficial effects on the soil, it provides easily assimilable nitrogen of organic origin to the successor plants. For organic farmers, who cannot use synthetic fertilizers, vetch is an excellent pre-sowing crop.

6. LIST OF PUBLICATIONS RELATED TO THE DISSERTATION

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Subject: PhD Publication List

Candidate: Edit Kosztyuné Krajnyák
Doctoral School: Kálmán Kerpely Doctoral School
MTMT ID: 10058307

List of publications related to the dissertation

Hungarian book chapters (1)

1. Vágvölgyi, S., Szabó, B., **Kosztyuné Krajnyák, E.**: A pillangósvirágú takarmánynövények jelentősége a savanyú homoktalajok fenntartható hasznosításában. In: Hangsúlyok a térfejlesztésben. Szerk.: Nagy János, Tranzit-Ker Zrt., Debrecen, 399-409, 2018. ISBN: 9786150020723

Hungarian scientific articles in Hungarian journals (3)

2. **Kosztyuné Krajnyák, E.**, Szabó, B., Csabai, J., Tóth, C., Irinyiné Oláh, K., Vágvölgyi, S., Pepó, P.: A szöszösbükköny (Vicia villosa Roth.) és a tritikálé (X Triticosecale Wittmack) jelentősége a fenntartható biológiai talajvédelemben a Nyírségben. *Növénytermelés. 72* (1), 1-19, 2023. ISSN: 0546-8191.

3. Szabó, M., Álmos, G., Bodrogi, A., Csabai, J., **Kosztyuné Krajnyák, E.**, Szabó, B., Tóth, C.: A szöszös bükköny gyomflórájának vizsgálata ökológiai gazdálkodásban. *Georgicon Agric. 24* (1), 83-88, 2020. ISSN: 0239-1260.

4. Szabó, B., **Kosztyuné Krajnyák, E.**, Szabó, M., Csabai, J., Tóth, C., Varga, C.: Pillangósvirágú növények magtermesztésének növényvédelmi tapasztalatai ökológiai termesztésre átállt gazdaságban. *Georgicon Agric. 24* (1), 89-93, 2020. ISSN: 0239-1260.

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