South Western Journal of
Horticulture, Biology and Environment
P-Issn: 2067- 9874, E-Issn: 2068-7958

Vol.14, No.1, 2023
pp. 14-27
Art.no. e23102

INVESTIGATION OF THE EFFECT OF SOWING TIME ON ONE OF THE KEY CROPS OF SUSTAINABLE LAND USE, THE HAIRY VETCH (*Vicia villosa* Roth.): GROWTH INDICATORS AND YIELD ELEMENTS IN NYÍRSÉG REGION OF EAST HUNGARY

Edit Kosztyuné KRAJNYÁK[1]*, Béla SZABÓ[1], Judit CSABAI[1], Zsolt Tibor HÖRCSIK[1], Tímea MAKSZIM GYÖRGYNÉ NAGY[1], Gyuláné GYÖRGYI[2], István HENZSEL[2], Péter PEPÓ[3]

[1]University of Nyíregyháza, Institute of Engineering and Agricultural Sciences, Department of Agricultural Sciences and Environmental Management, H-4400, Nyíregyháza, Sóstói Str. 31/b.
[2]University of Debrecen, IAREF, Research Institute of Nyíregyháza, H-4400, Nyíregyháza, Westsik V. Str. 4-6
[3]University of Debrecen, Kálmán Kerpely Doctoral School, H-4032, Debrecen, Böszörményi Str. 138.
*Corresponding author: E. Kosztyuné Krajnyák, E-mail: krajnyak.edit@nye.hu

ABSTRACT. *Leguminous crops, whose species characteristics and agronomic values allow their incorporation into sand farming, are of great importance for the environmentally friendly utilization of the acidic sandy soils of Nyírség. Among the legume cultivars that can be grown on acidic sandy soils, the hairy vetch is of outstanding importance, which is also been grown as green manure, green fodder, and seed, in Hungary, for more than a hundred years. Our observation aimed to examine, in a field micro-parcel experiment, at different sowing times, in six replicates, at three different recording periods, the plant height, the root length, the number of the Rhizobium root-nodules formed on the main and lateral roots, the number of seeds, the weight of the seeds, and the thousand kernel weight of the hairy vetch. From our experimental results, we found that the average height of the plants before the onset of winter, at the sowing time in late September, was between 11 and 18 cm, while the root length ranged from 16 to 26 cm. In the same phenophase (before winter) and sowing time, the highest number of Rhizobium nodules was measured on the main root (9.4–11.5), while the most efficient nodule formation on the lateral roots was in the budding period (13.7–27.6), also in the sowing time of September 20. In the studied years, the data on the number of pods per plant of hairy vetch showed an increasing trend with sowing time (5.6–12.2 pc/plant). The same increasing trend was observed for the number of* *seeds per plant (13.9–34.6 pc/plant). The highest seed weight (0.57–0.79 g) was obtained at the last sowing date. The results presented above also confirm that the cultivation of hairy vetch should become more and more important for sustainable land use.*

KEYWORDS: *hairy vetch, morphological parameters, Rhizobium nodules, crop elements, sandy soil*

INTRODUCTION

Since the term "sustainable development" was coined in 1987, research on sustainable land use has been a top emphasis (Aznar-Sánchez et al. 2019, Velten et al. 2015). Sustainable arable farming, with all of its agrotechnology components, is considerably different from today's industrial farming (Lichtfouse 2009). Industrial production has become so damaging that it is evident that arable crop production based on it cannot be sustained, making this kind of agriculture unsustainable (Adler 2002). 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 (Gomiero 2016, Lal 2015). Intensive tillage has resulted in the compaction of soils. Soil compaction is a form of physical degradation of soil where the physical properties of the soil are altered in terms of bulk density, porosity, element mobility, nitrogen-carbon cycling, and greenhouse gas emissions. Soil compaction reduces soil biodiversity, enzyme activity, soil fauna, and soil flora (Piccoli et al. 2022, Nawaz et al. 2013).

A variety of legume crop rotations are utilized in agricultural zones, which is significant in agriculture (Ali et al. 2012).

The most visible signs of climate change in Hungary are a major drop in water supplies and an increase in temperature, both of which lead to regular droughts. To maintain sustainability in cultivation technology systems, it is critical to establish an ideal soil-plant connection that minimizes the negative impacts of extremes on cultivated crops (Nagy & Nagy 2018). Crop rotation, which is important for maintaining and improving soil fertility, is the cornerstone of sustainability in arable crop production. Crop rotation helps to reduce the depletion of the soil's nutrient and water resources, allowing for a more professional and diverse use of the soil (Chahal et al. 2021). The inclusion of legumes is critical for soil sustainability. A considerable boost in yield can be gained by incorporating these plants into the crop rotation (Sárvári 2019, Meena & Lal 2018, Das et al. 2018). In recent decades, the number of alternative crops in the agricultural structure of arable crop production has declined dramatically. Nonetheless, these crops are important to agriculture in terms of economics, the environment, and land use (Pepó 2019).

Legumes add nitrogen to the soil and enhance its structure (Bekuzarova et al. 2020). Agricultural lands have been estimated to fix 80% of the biologically fixed N_2 thanks to leguminous symbiotic relationships (Mendoza-Suárez et al. 2020). Legume green manuring is not only a good approach for increasing crop yield and mitigating CH_4 emissions, but legume cultivation also increases the biomass of the soil microbial community (Raheem et al. 2022, Zhao 2015). The quantity of nodule number or mass, as well as the ratio of N-fixation rate to nodule respiration, are direct measurements of *Rhizobium* bacteria efficiency (Denison 2021). Lupin (*Lupinus*), white sweet clover (*Melilotus albus* L.), hairy vetch (*Vicia villosa* Roth.), and Crimson clover (*Trifolium incarnatum* L.) are the most important green manure legumes cultivated on weak, acidic, light-sandy Hungarian soils. Hairy vetch is one of Hungary's most common green manure plants (Kahnt 1986, Kosev & Georgieva 2021, Bakhtiyari et al. 2020, Vágvölgyi et al. 2018).

The hairy vetch is not only green manure but could be a cover crop too. Cover crops play a critical role in conservation and sustainable agriculture due to their well-documented benefits for both soil and crop productivity (Veloso et al. 2018).

Nowadays, the task of agricultural production is to keep sustainability and environmental protection in mind, in addition to the traditional functions (supplying the population with food and employment). Given the importance of leguminous plants in environmental management, it would be reasonable to encourage producers, at a higher level of government to grow them as green manure. Hairy vetch, as a leguminous soil protection plant, is justified for cultivation on low-yielding sandy soils (Gondola & Szabóné 2010).

The main hypothesis of our study were the following: Hypothesis 1 (H1): Among the overwintering annuals, the hairy vetch has an excellent response to sowing time; Hypothesis 2 (H2): Rhizobium nodule formation and growth are most intensive in early sowing; Hypothesis 3 (H3): The sowing date has an effect on the crop elements, and early sowings form vegetative stands, whereas late sowings form generative stands. Based on our research, we set the following objectives:1. to analyze the effect of sowing time on the morphological parameters (growth indicators) of the hairy vetch in a culture pot experiment; 2. to study of growth dynamics of Rhizobium nodules on the roots of hairy vetch in a culture pot experiment; 3. to analyze the effect of sowing time on the generative yield elements (pod number, seed number, seed weight, and thousand kernel weight) of hairy vetch in a culture pot experiment

MATERIALS AND METHODS

Our experiment of micro-parcel type was set up in the demonstration garden of the University of Nyíregyháza. Small pots with 27 cm in height x 29 cm in diameter (average) and a capacity of 20 liters were submerged in the open field. We set up the research in six replicates. We brought the soil from the study farm of the University of Nyíregyháza.

Three experimental variants were used for pure sowing: vetch (20 seeds); triticale (62 seeds), as well as mixed sowing of the seeds of these two plants (13 vetch and 26 seeds of triticale).

The hairy vetch is an overwintering plant. The first experimental year was sown in autumn 2019 and harvested in 2020. The second trial year was sown in autumn 2020 and harvested in 2021.

The study was conducted in 2019-2020 and 2020–2021, with three sowing dates in each year (September 20, October 10, and October 30). The environment of the culture pots was also used in order to avoid the border effect. Pesticide treatment and fertilization were not used in the area.

Of the plants involved in the experiment, only the pure-sown vetch was investigated throughout our work. Its variety was Hungvillosa. This cultivar has long, hairy leaves and stems. It has the advantage of producing a huge green mass even in early spring and on poor soils. In addition, it has excellent tillering and winter hardiness (Péter 2009, Teasdale et al. 2004). It is low-maintenance in terms of climate and tolerates drought well. Green yields range from 25 to 60 tons per acre. 1-1,5 t/ha seed yield (Nemzeti Agrárgazdasági Kamara 2019). The soil characteristics are shown in Table 1. From the results of the soil study, it can be clearly seen that the soil, which was filled in the pots, was sandy and strongly acidic.

During the recordings, 10 plants were examined at all three sowing times. The recording took place three times in both years, before the onset of winter

(11/28/2019; 8/12/2020), during budding (6/23/2020; 6/5/2021), and at harvest (30/06/2020; 9/9/2021). The plants selected from the pots were processed in a laboratory. Root cleaning was done with caution to avoid damaging the *Rhizobium* nodules. Growth indices measurements were performed on the cleaned plants, plant height and root length were measured, and the number of *Rhizobium* nodules on the main and secondary roots was also counted. The pods and seeds in them were removed from the mature plants (during harvest) and counted. We also measured seed weight and thousand kernel weight.

Table 1. The results of the soil examination of the experimental land (2019-2020, 2020-2021) (Source: Hungarian Horticultural Propagation Material Non-profit Ltd.)

Parameter	2019-2020	2020-2021
Sampling depth (cm)	0-30	0-30
pH-KCl (-)	4.44	4.22
Soil plasticity according to Arany (KA)	27	27
Total watersoluble salt (m/m%)	<0.02	<0.02
$CaCO_3$ (m/m%)	<0.1	<0.1
Humus content (%)	0.89	1.14
NO_3^--N+NO_2^--N (mg/kg)	18.7	17.9
SO_4^{2-}-S (mg/kg)	<50	<50

Nyíregyháza is located in the part of the Great Plain where the weather conditions are partly in transition between a warm-dry climate and a moderately warm-dry climate. Typically, however, winter is cold. Its climate is continental. The Nyírség and the Upper Tisza region is one of the most warming areas in Hungary, due to climatic changes (Borsy 1961). Table 2 shows the precipitation (mm) and temperature (℃) data collected during the growing season of the analyzed years. When we compare the precipitation data collected across the two-year growth season, we can see that the annual precipitation amounts were nearly identical exceeding the national average of more than 130 years in both years. However, we find differences in the distribution of precipitation. A considerable amount of precipitation (138.2 mm) fell in November and December 2019, well exceeding the 50-year national average. This amount of precipitation had a favorable effect on the initial development of the vetch. However, in the spring, a rather dry period ensued. The amount of precipitation did not reach the 50-year average. This had a negative effect on the flowering and fruit set of the vetch. Precipitation arrived in large quantities, albeit belatedly, on the ripening vetch in June. In September and October 2020, a significant amount (175.8 mm) of precipitation was measured. The year 2021 also started with a lot of rainfall, and there was a significant amount of rain in the spring months as well. The precipitation values measured, with the exception of August, November, March, June, and July, were substantially above the long-term national average.

The annual average values of the temperature data showed a similar result in the studied years (10.6°C and 10.5°C), thus exceeding the long-term national average (9.5°C). With the exception of September, the temperature data for the autumn months in both years was above the 50-year average, which was beneficial to the hairy vetch's initial growth and development. In the spring, this trend continued, which, together with the lack of rainfall in the 2019 sowing year, resulted in soil dehydration. Because of the distribution of precipitation, spring weather in 2020–2021 was more pleasant.

Table 2: Some important meteorological data (Nyíregyháza, 2019-2020, 2020-2021) (Source: measurements done by DE AKIT Nyíregyháza Research Institute)

Months	Precipitation (mm)			Temperature (℃)		
	2019-2020	2020-2021	Average (1870-2002)	2019-2020	2020-2021	Average (1870-2002)
August	15.3	40.1	65	22.9	22.5	19.8
September	26.8	72.3	43	16.6	17.2	15.5
October	22.6	103.5	44	11.7	11.9	9.9
November	85.4	20.8	46.5	8.9	4.9	4.2
December	52.8	41.9	40.5	3	4.1	-0.4
January	23.3	61.9	29.5	-0.9	1.2	-2.4
February	44.3	59.2	30	4.6	1.5	-0.1
March	26.6	18.7	30	6.6	4.9	4.6
April	4.1	59.7	39.5	11.5	9	10.7
May	38.4	90.6	54	14.3	14.9	15.9
June	175.1	14.9	76	20	22.1	19
July	70.2	45.4	66.5	21	24.1	20.6
Total/Average	584.9	629	564.5	11.6	11.5	9.7

In our field trial, we used an independent t-test to examine the differences between the measured parameters in two sowing years (2019-2020, 2020-2021), in 3 phenophases (pre-winter, bud break, harvest), and within each phenophase in 3 sowing dates (20 September, 10 October, 30 October). The first stage of our significance analysis was to compare the measurement dates of 20 September and 10 October. 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 divided these three stages because we thought it was vital to spot changes in the process as well as compare the pattern between the extreme sowing dates (20 September and 30 October).

The data were evaluated using IBM SPSS Statistics 23 version and the spreadsheet program Microsoft Excel 2016. A two-sample t-test for the expected value was used as statistical analysis. Our results were compared at a significance level of $p \leq 0.05$. Before the t-test tests, we tested the distribution of the initial data with a normality test in all cases. In all cases, our tests were based on a small sample, and we worked with a sample of 10 elements in a culture pot experiment.

RESULTS

The initial growth of the plants was significantly affected by sowing time (Table 3).

Table 3. Effect of sowing time on hairy vetch plant height (cm) and statistical significance ($p \leq 0.05$).

	Plant height (cm)					
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	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
Time of observation	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

Plant heights measured before the onset of winter declined significantly in both years as sowing time advanced. We observed clear changes in the values measured at budding during the studied year. This pattern is no longer visible at harvest time. The plant's height equalizes.

The change in root length shows a similar trend to plant height (Table 4). In both years, before the onset of winter, the root length of the earliest sown plants was the longest. We saw distinct differences around the time of budding in 2020. By the time of budding in 2021, inequalities had vanished. At the time of harvest, on average over the last 2 years, no clear trend can be identified.

In the pre-winter period, the number of *Rhizobium* nodules on the main and secondary roots tends to decrease as the sowing period progresses (Table 5-6). The earlier we sowed the plants, the more nodules appeared on the roots. At budding, there was no significant difference in all cases. At the time of harvest, a significant portion of *Rhizobium* nodules will disappear, so at the same time, measurable differences will disappear.

In both years, the number of pods per plant and the number of seeds were much higher in the latest sown plants (Table 7). Of course, the number of seeds per plant was also higher in the late sowing period.

The thousand kernel weight of early sown plants fell short of the values measured in the two later sowing periods (Table 8).

Table 4. Effect of sowing time on hairy vetch root length (cm) and statistical significance ($p \leq 0.05$).

	Root length (cm)					
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	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
Time of observation	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

Table 5. Significance test of *Rhizobium* number of the main root (p≤ 0.05)

	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
Time of observation	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 6. Number of *Rhizobium* nodules on the lateral root (pc - pieces) and statistical significance (p≤0.05).

	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
Time of observation	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

Table 7. Changes in the number of pods and seeds (pc - pieces) and statistical significance (p≤0.05).

	Number of poods (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
Time of observation	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

Table 8. Seed weight and thousand kernel weight (g) and statistical significance (p≤0.05).

	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
Time of observation	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

DISCUSSION

The response of the hairy vetch to the sowing time is excellent among the overwintering annual plants, as the quantifiable plant features and attributes clearly reflect the effect of changes in sowing time. The morphological parameters of the hairy vetch sown at different times showed significant differences in the phenological stages we examined. Knowledge of these differences is important from an agronomic point of view because it enables one to deduce the dynamics of vegetative and generative biomass formation, the development of the plant-soil relationship, and the intensity of nitrogen collection in *Rhizobium*.

In the case of September sowing, before winter sets in, visible plant growth (11-18 cm), develops on the soil surface with a large number of root nodules on the early main (9.4-11.5 pc) and lateral roots. When grown as a green manure, vetch is the most effective at this sowing time for protecting the soil and enriching it with nitrogen. The formation of vegetative biomass (green mass) is also highest at this sowing time, which is also important for the production of mixed green fodder. Legány's fall fodder mixture (rye/common wheat/ hairy vetch/Hungarian vetch/ crimson clover) is sown in Hungary from early August (Szentmihályi 1964, Kiss 1965). A well-strengthened herd develops in the autumn on the aforementioned mixed fodder, which is an important aspect for wintering (Székely & Tóth 1961). It was proven in a 6-year study (2004-2009) in the Pacific Northwest of the United States that hairy vetch and rye vetch combinations sown in mid-September generated higher biomass weights than those sown 2.5 weeks later. Delaying sowing by 2.5 weeks reduced average winter soil cover by 65%, biomass by 50%, and N accumulation by 40% (Lawson et al. 2015). In the southern United States, sowing in October reduced biomass yields by 20% at flowering and 43% at harvest in the southern United States for the grass vetch crop (Teasdale et al. 2004).

Our experiments confirm the above, as later sowing times result in a significant reduction in the green mass produced until harvest, as well as in root mass and *Rhizobium* nodule counts. Harvest phenophase root lengths are significantly shorter than pre-winter and budding values. The decomposition of the root system of the maturing plant and the onset of mineralization leads to the absorption of the roots. In early sowing, the number of rhizobium nodules formed on the main root and later roots was higher than in late sowing. This difference is evened out by the time of budding and fruiting, but the larger *Rhizobium* nodule provides a greater supply of nitrogen for spring plant development (Batstone et al. 2020, Oono et al. 2020). This is because the formation of green mass, which is important for soil conservation, is most evident in early autumn sowings. This high number of rhizobia provides the vegetative biomass mass for early sowings. The development of seed yield is influenced not only by the nitrogen content of the soil but also by a number of other factors, which explains why rhizobium number and soil nitrogen content do not show a linear positive correlation with seed yield.

The yield determinants (number of pods, number of seeds, and seed weight) were highest at the latest sowing period, implying that late sowings are generating a generative kind of crop that is vital for seed production. In later sowings, the thousand kernel weight is likewise larger, increasing the seed's utility value. Studies in southwestern Australia have shown that within the genus *Vicia*, the highest seed yields were produced by *Vicia sativa* varieties. Seed yields here exceeded 1.6 t/ha. The yield of *Vicia villosa* was much lower than this (Siddique & Loss 1996). Hairy vetch has a poorer seed yield under field conditions, with a seed yield of 0.5-0.8 t/ha on compacted soils, especially when rainy, and 0.4-0.5 t/ha on poor soils (Dobránszki 2002). This is confirmed by the results measured in the early sowing time in our micro parcel experiment.

REFERENCES

Adler, T. (2002): Harmful Farming. Environmental Health Perspectives 110(5): 256-257.

Ali, M., Kumar, N., Ghosh, P.K. (2012): Milestones on agronomic research in pulses in India. Indian Journal of Agronomy 57(3): 52-57.

Aznar-Sánchez, J.A, Piquer-Rodríguez, M., Velasco-Muñoz, J.F., Manzano-Agugliaro, F. (2019): Worldwide research trends on sustainable land use in agriculture. Land Use Policy 87: 104069.

Bakhtiyari, F., Zamanian, M., Golzardi, F. (2020): Effect of mixed intercropping of clover on forage yield and quality. South Western Journal of Horticulture, Biology and Environment 11(1): 49-66.

Batstone, R.T., Peters, M.A., Simonsen, A.K., Stinchcombe, J.R., Frederickson, M.E. (2020): Environmental variation impacts trait expression and selection in the legume–rhizobium symbiosis. American Journal of Botany 107(2): 195-208.

Bekuzarova, S.A., Kozyrev, A.K., Shabanova, I.A., Lushenko, G.V., Weissfeld, L.I. (2020): Enhancing of nitrogen fixation by legumes. BIO Web of Conferences 23: 02006.

Borsy Z. (1961): A Nyírség természeti földrajza. Akadémiai Kiadó, Budapest.

Chahal, I., Hooker, D.C., Deen, B., Janovicek, K., Van Eerd, L.L. (2021): Long-term effects of crop rotation, tillage, and fertilizer nitrogen on soil health indicators and crop productivity in a temperate climate. Soil and Tillage Research 213: 105121.

Das, A., Devi, M.T., Babu, S., Ansari, M., Layek, J., Bhowmick, S.N., Yadav, G.S., Singh,

R. (2018): Cereal-legume cropping system in Indian Himalayan region for food and environmental sustainability. pp: 33-76. In Meena, R., Das, A., Yadav, G., Lal, R. (eds.) Legumes for Soil Health and Sustainable Management. Springer, Singapore.

Denison, R.F. (2021): Legume-imposed selection for more-efficient symbiotic rhizobia. Proceedings of the National Academy of Sciences 118(22): e2107033118.

Dobránszki, J. (2002): A szöszösbükkönytermesztés technológiája. pp. 206-214. In: Dobránszki J. (ed.) A Nyírségi burgonyatermesztés fejlesztése, homokhasznosítás tájba illő növényekkel, Nyíregyháza.

Gondola, I., Szabóné, Cs.K. (2010): Szöszösbükköny (*Vicia villosa* Roth.). pp. 131-151. In: Gondola I. (ed.) Az alternatív növények szerepe az Észak-alföldi Régióban, Nyíregyháza.

Gomiero, T. (2016): Soil degradation, land scarcity and food security: Reviewing a complex challenge. Sustainability 8(3): 281.

Kahnt, G. (1986): Zöldtrágyázás. Mezőgazdasági Kiadó. Budapest.

Kiss, I. (1965): Alapvetően fontos a folyamatos zöldtakarmányozás. Magyar Mezőgazdaság 20(29): 15-17.

Kosev, V.I., Georgieva, N. (2021): Multivariate analysis of white lupine (*Lupinus albus* L.) genotypes. South Western Journal of Horticulture, Biology and Environment 12(2):75-87.

Lal, R. (2015): Restoring soil quality to mitigate soil degradation. Sustainability 7(5): 5875-5895.

Lawson, A., Cogger, C., Bary, A., Fortuna, A. M. (2015): Influence of seeding ratio, planting date, and termination date on rye-hairy vetch cover crop mixture performance under organic management. PloS ONE 10(6): e0129597.

Lichtfouse, E. (2009): Sustainable agriculture as a central science to solve global society issues. pp. 1-3. In: Lichtfouse E. (ed.) Organic Farming, Pest Control and Remediation of Soil Pollutants. Sustainable Agriculture Reviews. Vol. 1. Springer.

Meena, R.S., Lal, R. (2018): Legumes and sustainable use of soils. pp: 1-31. In: Meena, R., Das, A., Yadav, G., Lal, R. (eds.), Legumes for Soil Health and Sustainable Management. Springer, Singapore.

Mendoza-Suárez, M.A., Geddes, B.A., Sánchez-Cañizares, C., Ramírez-González, R.H., Kirchhelle, C., Jorrin, B., Poole, P.S. (2020): Optimizing Rhizobium-legume symbioses by simultaneous measurement of rhizobial competitiveness and N_2 fixation in nodules. Proceedings of the National Academy of Sciences 117(18): 9822-9831.

Nagy, J., Nagy, O. (2018): Fenntartható agrárgazdálkodás a klímaváltozás tükrében. Magyar Tudomány 179(9): 1327-1335.

Nemzeti Agrárgazdasági Kamara (2019): Fehérjenövény katalogus 2019. Nagymagvú hüvelyes rendezvényen bemutatott fehérjenövények. Magyar Szója Nonprofit Kft.

Nawaz, M.F., Bourrie, G., Trolard, F. (2013): Soil compaction impact and modelling. A review. Agronomy for sustainable development 33(2): 291-309.

Oono, R., Muller, K.E., Ho, R., Jimenez Salinas, A., Denison, R.F. (2020): How do less-expensive nitrogen alternatives affect legume sanctions on rhizobia? Ecology and Evolution 10(19): 10645-10656.

Pepó, P. (2019): Előszó. pp. 5-6. In: Pepó, P. (ed.), Alternatív növények. Integrált növénytermesztés 3. Mezőgazda Lap- és Könyvkiadó, Budapest.

Piccoli, I., Seehusen, T., Bussell, J., Vizitu, O., Calciu, I., Berti, A., Bolinder, M.A. (2022):

Opportunities for mitigating soil compaction in Europe—Case studies from the soil care Project Using Soil-Improving Cropping Systems. Land 11(2): 223, 10.3390/land11020223.

Péter, M. (2009): A zöldtrágyázás talajállapotra és utóveteményre gyakorolt hatásainak vizsgálata. PhD Thesis. Corvinus University.

Raheem, A., Wang, T., Huang, J., Danso, F., Bankole, O.O., Deng, A., Zhang, W. (2022): Leguminous green manure mitigates methane emissions in paddy field by regulating acetoclastic and hydrogenotrophic methanogens. European Journal of Soil Biology 108: 103380.

Sárvári, M. (2019): Tápanyag-gazdálkodás. pp. 249-262. In: Pepó, P. (ed.), Általános növénytermesztési ismeretek. Integrált növényermesztés 1. Mezőgazda Lap- és Könyvkiadó, Budapest.

Siddique, K.H.M. Loss, S.P. (1996): Growth and seed yield of vetches (*Vicia* spp.) in south-western Australia. Australian Journal of Experimental Agriculture 36: 587–593.

Szentmihályi, S. (1964): Az őszi keveréktakarmányok jelentőségéről. Magyar Mezőgazdaság 19(35):17-18.

Székely, J., Tóth, J. (1961): Szálastakarmányok termesztése és felhasználása. Mezőgazdasági Kiadó. Budapest.

Teasdale, J.R., Devine, T.E., Mosjidis, J.A., Bellinder, R.R., Beste, C.E. (2004): Growth and development of hairy vetch cultivars in the northeastern United States as influenced by planting and harvesting date. Agronomy Journal 96(5): 1266-1271.

Vágvölgyi, S., Szabó, B., Kosztyuné, K.E. (2018): A pillangósvirágú takarmánynövények jelentősége a savanyú homoktalajok fenntartható hasznosításában. pp. 399-409. In: Nagy, J. (ed.), Hangsúlyok a térfejlesztésben. Debrecen.

Veloso, M.G., Angers, D.A., Tiecher, T., Giacomini, S., Dieckow, J., Bayer, C. (2018): High carbon storage in a previously degraded subtropical soil under no-tillage with legume cover crops. Agriculture, Ecosystems & Environment 268: 15-23.

Velten, S., Leventon, J., Jager, N., Newig, J. (2015): What is sustainable agriculture? A systematic review. Sustainability 7(6): 7833-7865.

Zhao, J., Zeng, Z., He, X., Chen, H., Wang, K. (2015): Effects of monoculture and mixed culture of grass and legume forage species on soil microbial community structure under different levels of nitrogen fertilization. European Journal of Soil Biology 68: 61-68.