LEGUME PERSPECTIVES

Legume cover crops uncovered

Their role in cropping systems

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Front cover:
Mixture of vetches and cereals.
Photo courtesy Jaume Lloveras.

EDITORIAL

We are delighted to present the 20th issue of Legume Perspectives devoted to the use of legumes as cover crops. This issue covered various aspects of their application, such as the effect on soil health, soil water and nitrogen status, ecosystem services, suitable legume species for covering the soil, etc. The main target in soil cover is soil conservation, fertilization and protection against erosion especially in the context of climate change. Therefore, we hope that the information and topics presented in this issue will be useful to researchers of the International Legume Society and generate further cooperation and multidisciplinary research. This issue presents articles from different regions of the world, and we hope that you find all contributions informative and interesting.

This issue was created during the global COVID-19 pandemic, a difficult new chapter in human history, and we are therefore more than thankful to all authors who gave their contributions. We wish you all good health. Be safe!

Branko Ćupina
Svetlana Vujić
Managing editors of the issue

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Carte blanche to…

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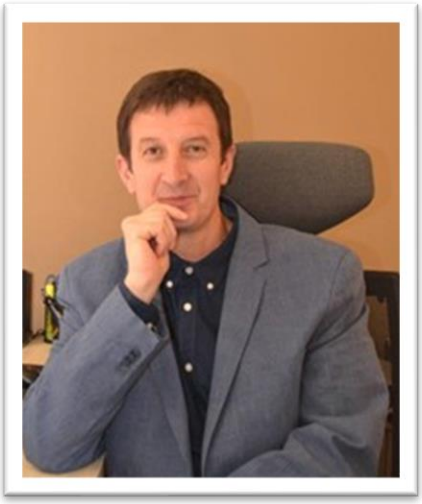
Cover crops were introduced into the crop rotation as an efficient measure of soil protection and due to their multiple ecosystem services. Cover crops could be defined as a response to different agricultural practices that cause different forms of soil degradation and raise the question of sustainable food production. Therefore, along with the growth of the human population, the need to preserve agricultural land has also increased. The primary goal of soil cover is to maintain or improve the physical and biochemical properties of the soil.

The articles in this issue gave a short insight on legumes as cover crops and their possibilities. The focus on legumes as cover crops is a result of the fact that of the many plant groups which can be grown as soil covers, legumes give a special bonus to a cropping system - by symbiosis they contribute additional N to the nutrient cycle. Furthermore, legumes as cover crops can be easily included in the crop rotation as green manure or living mulch, but they also offer harvest possibilities such as forage, grazing, or seed production. However, the cultivation of cover crops is either neglected or entering very slowly to farms around the world. Therefore, continuous efforts should be made to recognize all the opportunities and achievements provided by legume cover crops based on their broad environmental impacts and economic justification.




Left to right: Branko Ćupina and Svetlana Vujić.

Managing nitrogen with legume cover crops in crop rotation

Svetlana Vujić[1], Branko Ćupina[1], Djordje Krstić[1], Nedeljko Tica[1]

Abstract: Legumes worldwide are suitable cover crops since they contribute to soil improvement, biodiversity and ecological-friendly production on the farm. Compared to other species, legumes are getting priority due to their possibility to enrich soil fertility through symbiotic nitrogen fixation. However, there are differences between the amount of soil nitrogen incorporated in the soil by green manure or residues and the amount of nitrogen taken up by the subsequent crop. In a set of trials at the University of Novi Sad, Faculty of Agriculture, the effect of winter legume cover crops used as green manure (legume, cereal, legume/cereal mixture), fertilization treatments and control (no cover crops, no fertilization) on nitrogen budget after main crops (Sudan grass and silage corn), was analyzed by apparent nitrogen remaining in the soil (ARNS, kg N ha^{-1}). ARNS values ranged as legume>legume/cereal mixture>cereal, and the general conclusion is that legume cover crops positively affect nitrogen contribution for the subsequent main crop, but it strongly depends on amount and schedule of precipitation after cover crops incorporation in the soil.

Key words: cover crops, green manure, soil properties, nitrogen, ARNS

Introduction

The main fact that goes with the term cover crops is that they are used to improve soil properties and increase biodiversity. The improvement of soil properties is reflected through soil coverage and reduced erosion, improved soil structure, increased organic matter content, nitrogen supply, reduced leaching, and nutrient loss, etc. By incorporating cover crops in crop rotation, the biodiversity increases on the farm, while the number of weed species is reduced. Cover crops benefit depends on the cover crop species or species mixture, soil characteristics and climate. The most commonly used species as cover crops in diverse cropping systems belong to the following families, *Fabaceae*, *Brassicaceae*, and *Poaceae*, but only legume species can be used as a high nitrogen soil supplier. Their utilization in the cropping system, conventional, sustainable, or organic, provides environment-friendly services, especially in maintaining or enriching soil fertility through symbiotic nitrogen fixation (1). Annual legume cover crops are short-growing crops and can be used for forage or as green manure, thus they easily fit into existing crop rotation. However, practice of growing of cover crops and their introduction in crop rotations are not so popular among farmers primarily because it includes crops that do not enable significant economic return, may reduce soil water availability, and often do not allow sufficient time for soil preparation for cash crops. Thus, researchers around the world are trying to demonstrate that the benefits of cover crops are significantly higher than the disadvantages.

Legumes and nitrogen budget

In Vojvodina province, Serbia, which is a temperate climate zone, common vetch (*Vicia sativa* L.) and field pea (*Pisum sativum* L.) are usually grown as legume cover crops. They are sown as winter crops since this is the fallow period between the most common cash crops in the region - corn and soybean. In several field trials performed by researchers from the University of Novi Sad, Faculty of Agriculture, the main objective was to analyze the effects of different winter cover crops used as green manure on the

Table 1. Nitrogen content in aboveground Sudan grass yield (N yield) and apparent N remaining in the soil (ARNS) after Sudan grass harvesting affected by cover crops and mineral fertilization treatments at locality Rimski Šančevi (average 2005-2006) (2).

Treatment	N yield in aboveground Sudan grass biomass (kg N ha^{-1})	ARNS after Sudan grass (kg N ha^{-1})
Field pea	123.91	165.26
Wheat	106.65	41.55
Field pea/Wheat	108.10	94.03
Oilseed rape	112.61	0.37
N1 - 40 kg N ha^{-1}	110.27	-25.40
N2 - 80 kg N ha^{-1}	132.52	29.00
Control (bare soil)	113.48	-59.48

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soil nitrogen budget and the effect on cash crop yield.

The experiments included annual legume, cereal, legume/cereal mixture, nitrogen fertilization and a control (bare soil) sown as winter crops on a carbonated chernozem soil and used as green manure by ploughing in the soil before main crop sowing in spring.

The selection of the crops was made to analyze amount of nitrogen which could be on disposal for cash crops and to compare it with the application of mineral nitrogen fertilizers. A detailed analysis of the experimental design and soil and weather conditions is given in Ćupina *et al.* (2, 3).

In the cropping systems several factors influence the nitrogen cycle. With the inclusion of legume crops, the nitrogen pathway can go in two directions, through the use as animal feed in the form of protein in forage (4) while the residues will be left in the soil, or the total accumulated nitrogen can be incorporated in the soil as green manure and used by subsequent crops after organic matter mineralization. Having in mind that there are differences between the amount of nitrogen incorporated in the soil by legumes and the amount of nitrogen taken up by subsequent crop, we calculated apparent N remaining in the soil (ARNS) following the main crop using the formula of Kramberger *et al.* (5).

In a trial with Sudan grass ARNS values were positive in all treatments with cover crops, while in control and N1 treatment (40 kg N ha^{-1}), ARNS values were negative as a result of the utilization of soil mineral nitrogen resources by Sudan grass plants (Table 1). As expected, the highest ARNS was in the treatment with field pea (165.26 kg N ha^{-1}), followed by the mixture of legume and cereal (94.0. kg N ha^{-1}). Decomposition of biomass and nitrogen release was much more intensive from pea than from the mixture, having in mind that a cereal component in the mixture causes a higher C/N ratio, which brings to slower mineralization and a lower amount of nitrogen released for the succeeding crop. In such conditions, there is an imbalance in the requirements of the cash crops and therefore an impact on their yield and quality (6). Nitrogen content in aboveground Sudan grass yield (or N yield) was significantly higher in treatments with field pea and N_2 (80 kg N ha^{-1}) as a result of higher nitrogen concentration in the soil during the Sudan grass growth.

During hydrological years 2011/2012 and 2012/2013, the effect of cover crops on yield and quality of silage corn was analyzed (Figure 1 and 2). In 2012, the ARNS values after the harvest of silage corn were higher in all three cover crops and N_2 treatment (Table 2). Generally, the experiment with silage corn has shown that when soil moisture is limited, even with optimum temperature values, the mineralization of cover crops organic matter plowed-in was very low and there was no nitrogen leaching into the lower layers. And not only leaching but also uptake by plants, having in mind that the N yield was almost half compared to control and fertilization treatments. Liebig *et al.* (4) pointed out that depending on the growing conditions, cover crops may have a negative impact on the subsequent crop, particularly with regard to conditions of extreme drought. In 2013, ARNS and N yield had different values than in 2012 due to more favorable weather conditions. Remaining nitrogen after silage corn was much higher with all cover crops included, but at the end, priority should be given to legume and legume/cereal mixture with a balance between obtained N yield and ARNS. Kramberger *et al.* (5) also concluded that legume cover crops had beneficial

Figure 1. Cover crop ploughing (Photo by Ćupina B., 2012).

Figure 2. Cash crop (silage maize) sowing (Photo by Ćupina B., 2012).

effects on corn N content. The N yield on bare soil or control was optimal but with a lower ARNS, having in mind that plants used soil mineral nitrogen as nitrogen source. Meisinger *et al.* (7) suggested an explanation for the lower ARNS values for treatments N1 and N2 by emphasizing that nitrate depletion may cause high yields under favorable weather conditions for denitrification and leaching.

Conclusion

The use of legume cover crops and their mixtures with non-legumes has numerous positive effects, like additional nitrogen, erosion reduction, improvement of soil properties, which vary significantly with water supply during cover crops and main crop growth (8). When incorporated in the soil, N accumulated in cover crops biomass becomes a part of the organic matter, which will be decomposed during a time, and becomes partially accessible to the subsequent crop (9). The benefit for the subsequent crop is 10-36% of total nitrogen in legume residues (9, 10).

In the long-term, legume cover crops enable two crucial aspects of plant production - preservation of soil fertility and protection against erosion. In that sense, they should be an essential link in crop rotation. Even on the fertile soil, as chernozem, continuous mineralization of organic matter without incorporations of plant biomass lead to a different form of soil degradation. Thus, there is no doubt that keeping soil cover during the fallow period with cover crops ensures production for the future.

Table 2. Nitrogen content in aboveground silage corn yield (N yield) and apparent N remaining in the soil (ARNS) after silage corn harvesting affected by cover crops and mineral fertilization treatments at locality Rimski Šančevi (2011-2012 and 2012-2013) (3)

	2011-2012		2012-2013	
Treatment	N yield in silage corn biomass (kg N ha^{-1})	ARNS after silage corn (kg N ha^{-1})	N yield in silage corn biomass (kg N ha^{-1})	ARNS after silage corn (kg N ha^{-1})
Common vetch	46.27	265.82	258.15	283.99
Triticale	54.60	232.81	208.33	395.48
Common vetch/Triticale	50.58	265.59	247.92	320.18
N1 - 120 kg N ha^{-1}	99.85	216.96	293.14	74.92
N2 - 160 kg N ha^{-1}	100.14	287.00	294.27	108.46
Control (bare soil)	102.74	192.43	235.76	93.44

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Legumes as winter cover crops in a temperate climate: the soil water status

Ksenija Mačkić[1], Borivoj Pejić[1], Đorđe Krstić[1], Svetlana Vujić[1], Branko Ćupina[1]

Abstract: Legume winter cover crops reduce soil water levels and storage efficiency, and by using easily available water in the soil, leave less available forms for the main crop. In this way, the benefits of replacing the fallow with forage cover crop should be sought by achieving an appropriate amount of forage even in drought years. Indeed, the negative soil moisture effects could be contradicted as soil quality improves with time and consequently the water properties of the soil. Additionally, in humid years legume cover crops dry out fields which allow entering the field earlier than on fallow. In conclusion, the legume winter cover should be implemented respecting the specific objectives of the production.

Key words: forage cover crops, soil water levels, water storage efficiency

Introduction

Cover crops (CC) may change soil water status either by changing the soil water properties or the available water levels (1). Cover decreases the impact of raindrops and runoff velocity. When the soil is covered with vegetation, it is protected from the direct impact of raindrops, since the impact energy is "amortized" on the plants and water is partially retained on the leaves and stem of plants; the movement of micro aggregates and particles is minimized, even during heavy rain. Evaporation from the soil is slower, so even if a crust is formed, it is weaker and thinner, because it is composed of a significant part of undestroyed macro aggregates.

The studies of the impact of CC on soil water properties show conflicting results (2). Clearly, the increased wet soil aggregate stability, improved water holding capacity, reduced rainfall-runoff, and improved infiltration, water retention, and available water levels are site-specific (3 - 5). By affecting the freeze-thaw processes CC can enhance spring snowmelt infiltration and deep percolation, but also reduce soil water storage at the beginning of the next growing season (6). Benefits to the main crop increase if the cover crops are terminated before the time of increased evaporative demands of the environment.

A cover crop depletes stored soil water before it is incorporated. In a dry year, this may alter the amount of water that is at the disposal to the main crop by decreasing the amount of plant-available soil water which could consequently produce problems with seedling growth and ultimately reduce the main crop yield (7). On the other hand, the consumption of water by the CC evapotranspiration dry out fields which allow entering the field earlier than on fallow, which can be beneficial in humid years.

Figure 1. Taking of plant and soil samples (Photo by Ćupina B., 2012).

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A short glance at the experiment

The climate is an underlying factor when considering the introduction of CC. In the temperate region of the northern part of Serbia, in Vojvodina province, with erratic precipitation, the use of CC is under debate.

The intensive conventional agriculture favors the growing of several winter and summer crops such as winter wheat, oat, corn, and soybean, which alternate with a fallow period. The fields of Vojvodina province cover the most fertile soil with a climate favorable for crop production. However, in such a production system a decrease of soil organic matter has been observed, as well as changes in soil structure, and increased compaction, which can affect the water properties of the soil.

The research set in Vojvodina province aimed to determine how much water remains in the soil before main crop sowing, and which cover crop, legume, cereal, or mixture is more efficient in water saving. Common vetch (*Vicia sativa* L., cv. Neoplanta), triticale (x *Triticosecale* Wittm. ex A. Camus, cv. Odisej), and their mixture were sown as winter forage cover crops. Cover crops were planted in the first half of October of 2011 and 2012 using seed rates of 120 kg ha^{-1} for vetch, 220 kg ha^{-1} for triticale, and 90 kg ha^{-1} of vetch and 30 kg ha^{-1} of triticale in the mixture (8). After the cover crops cutting in spring the soil was ploughed, seedbed prepared and the main crop (silage corn, cv. AS 31) was sown with a seeding rate of 65000 plants ha^{-1}. The control plot was ploughed in autumn and left as fallow during winter after what silage corn was sown in spring. The soil water content was measured before silage corn sowing and after silage corn harvest (Figure 1).

Soil water levels and storage efficiency of legume CC

The measured amount of water indicated lower soil water levels and storage efficiency (SE) on cover crop treatment plots than in the fallow (Figure 2).

Furthermore, by using easily available water in the soil, CC leave less available forms for the main crop. The soil on the fallow treatment was supplied with the easily available water throughout the spring pointing to a negative effect of CC on cash crops in dry years if the soil is not recharged with precipitation. The differences among

Figure 2. Effect of CC on the soil moisture. Plots after cover crops incorporation are light brown while control is dark brown, which means that CC, especially non legumes, deplete soil moisture (Photo by Ćupina B., 2012).

Table 1. Soil water content (SWC) and storage efficiency (SE) of winter cover crops and silage corn. The year 2012 had periods with severe and minor drought, while 2013 was characterized as a year with normal to moderately increased moisture.

Before silage corn sowing	Year	Legume	Cereal	Legume+Cereal	Bare soil
SWC (mm)	2012	243.6	251.4	218.3	344.6
	2013	255.4	234.0	236.4	299.7
SE	2012	70	72	63	99
	2013	59	62	65	93

Storage Efficiency % = (average 120cm soil water content before silage corn sowing ÷ average 120cm soil water content after winter) x 100

After silage corn harvest	Year	Legume	Cereal	Legume+Cereal	Bare soil
SWC (mm)	2012	149.1	141.1	154.6	157.4
	2013	206.4	197.2	197.7	220.1
SE	2012	61	56	71	46
	2013	81	84	84	67

Storage Efficiency % = (average 120cm soil water content after silage corn harvest ÷ average 120cm soil water content before silage corn sowing) x 100

cover crop treatments are more associated with weather conditions rather than cover crop species. Neither legume nor grasses CC showed improvement in available water levels (4). Legume forage winter CC had approximately equaled SE to that of a cereal crop; the lowest SE was on a mixture of legume and cereals (Table 1). Increased nitrogen availability in the mixture leads to greater cereal root development allowing deeper access to available soil water and nutrients (9, 10). The justification for using a mixture of legumes and grasses should be sought in the benefits of certain species in the mixture. Legumes, as deep-rooted CC, increase soil organic matter which in time results in increased absorbed water and along with root channels improves the main crop rooting depth to reach subsoil moisture (11). The reduction of water level in humid years could create favorable soil moisture conditions for the sowing of corn.

The corn SE is not related to the CC treatment (Table 1). After the silage corn harvest in a dry year, the water level was below the wilting point, supplying the plants only with hardly available water. Reducing soil water levels by the CC is limited to the initial growth of the main crop, but if the shortage of precipitation extends to the growing period the negative effect of the CC could be prolonged. The effect of a CC on soil water storage depends on the amount and timing of rainfall and the ratio between infiltration income and evapotranspiration losses during CC and main crop vegetation (7).

Higher SE on bare soil than on CC, regardless of the year, indicates the negative soil moisture effects from using CC that could be contradicted as soil quality improves with time. Replacement of fallow with CC might be practical in achieving an appropriate amount of forage even in drought years. The part of the forage will be provided in a favorable part of the year, reducing the uncertainty on corn production in the summer.

Conclusion

The introduction of legumes into the production system, as annual forage winter CC, is not justified in dry years from the standpoint of water conservation and is highly recommended in humid years, since water depletion is not critical. In the temperate region, legume winter cover crops contribute more to the quality of the soil than to water conservation. A locally well-designed cover-cropping system, legume or mixture, should be implemented respecting the specific objectives of the production.

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Legume cover crops as the secret key of a lost treasure

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Abstract: Introducing legumes as cover crops into the cropping system enables beneficial effects that could lead to soil protection. The main goal of cover crops growing is to cover soil during a certain period (especially during the winter) and to bring diverse benefits into the farm. Positive effects depend on the selection of plant species. In our research we found positive effects of legumes as cover crops on soil.

Key words: Legume, cover crop, soil

In recent decades, the soil has been exposed to intense anthropogenic influence. Intensive agricultural production often leads to disturbance of physical, chemical and biological properties of the soil. Year by year, decades by decades, soil lost its natural characteristics and qualities. In 2015, Food and Agriculture Organization (FAO) declared soil a non-renewable resource, and an invaluable natural asset, launching a global soil conservation campaign. Semedo (1) in his hypothesis "the 60 harvests left" points out that humanity is facing a crisis in which, if access to agriculture and resources is not changed, there are only 60 years left for food production. Because of that, there are many questions on how to preserve and even improve quality of soil.

In last decades, parallel to the development of the conventional form of agriculture, new designs of more sustainable agriculture appeared based on a large number of studies. In many countries due to the underdeveloped livestock production and thus the lack of animal manure, there is a growing need for the introduction of alternative organic fertilizers that will be beneficial from both economic and environmental aspects. Additionally, the absence of organic fertilizer entails the disturbance of physical, chemical and biological properties of soil (Figures 1 to 3). Many authors propose introducing legume cover crops into the cropping structure to enable beneficial effects that could lead to soil protection. Cover crops are cropped between two cash crops with the main goal of covering soil during a certain period (especially during the winter), bringing diverse benefits into the farm.

The positive effects of legumes as cover crops involve reduction of soil compaction (Figure 1) and bulk density (Figure 4)

Figure 1. Measurement of soil compaction in winter pea cover crops.

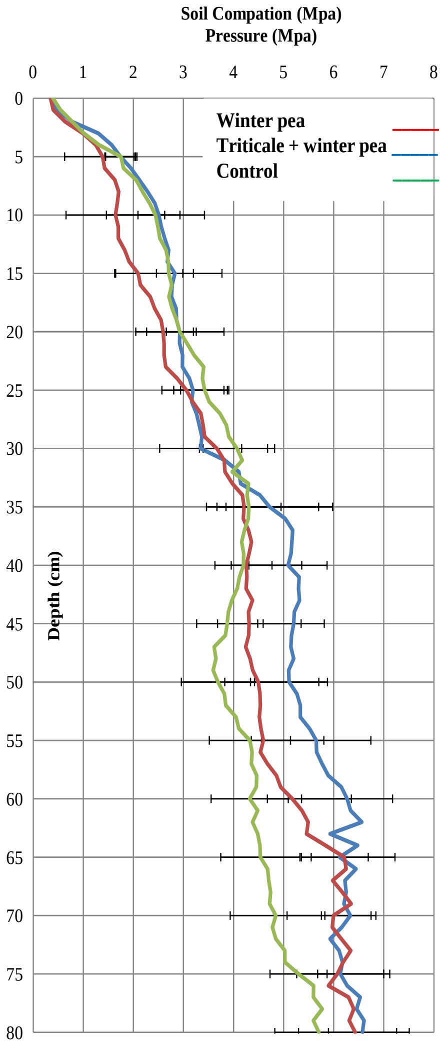

Figure 2. Soil compaction changes under the cover crops.

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Figure 3. Winter pea. Sampling shoot root ratio.

Figure 4. Sampling bulk density in mixed cover crops (winter pea and triticale).

prevention of soil erosion, increased content of labile organic carbon, reduction on the use of mineral fertilizers (Figure 5), etc. Indeed, legume cover crops represent the most effective method to decrease mineral fertilizer application in some sustainable crop production systems (Figure 5). Using as a green manure, legume plants with the possibility of nitrogen fixation and narrow C:N ratio can sometimes even replace the application of organic fertilizers. The continuous use of green manure increases the soil biogenicity and organic matter preservation (Figure 6). Many authors point out that the achievement of positive effects depends on the selection of appropriate plant species in cover crops. In our research, we also find positive effects of legumes as cover crops on soil (2-4).

Therefore, it is necessary to pay more attention to the adaptation of production technology to the use of legumes cover crops, as well as the selection of species combinations in order to find a secret key of a lost treasure – preserved soil for future generations.

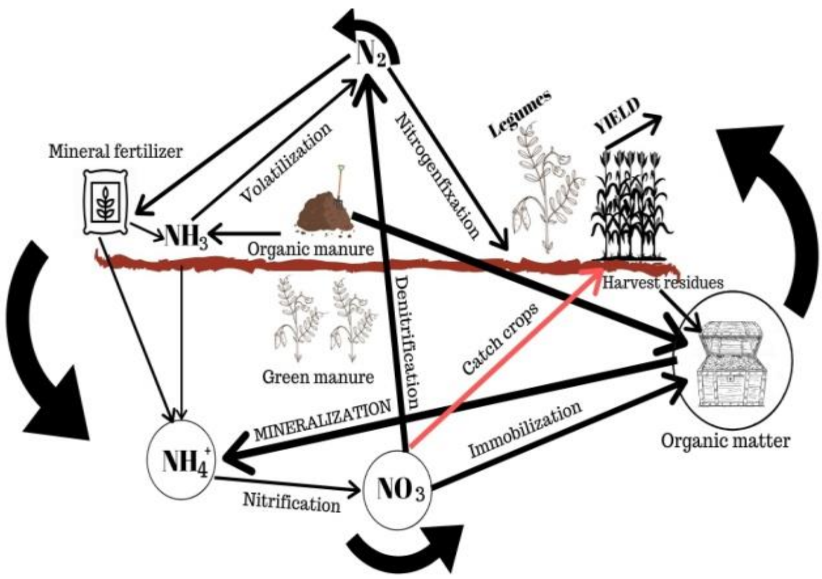

Figure 5. Nitrogen cycle with legume cover crops - Modified from Vojnov *et al.* 2020 (5).

Figure 6. Incorporation of legumes cover crops as green manure.

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Winter grain legumes are future-orientated crops in Central Europe

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Abstract: The winter forms of the grain legumes faba bean and pea are interesting crops in Central Europe in the context of climate change. Winter pea and winter faba bean were compared to their spring forms in a two-year field experiment in eastern Austria. Compared to the spring grain legumes, they have a longer growing period, can faster cover the soil, flower earlier and are earlier ready for harvest. The grain yield of winter pea was double as high and that of winter faba bean about 50% higher compared to their corresponding spring forms. Dinitrogen fixation of winter pea or winter faba bean was by about four or five times higher compared to their corresponding spring forms.

Key words: autumn-sowing, spring-sowing, dinitrogen fixation, *Pisum sativum*, *Vicia faba*

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Grain legumes are traditionally cultivated in Central Europe as spring crops, whereas winter forms are grown in countries with mild winters, e.g. in the Mediterranean basin (1), France and England (2).

The expected changes in agroclimatic conditions in the next decades due to climate change in Central Europe include higher year-round temperatures and a shift of rainfall pattern to more rainfall in winter and early spring, but less in summer (3). In such a scenario, the productivity of spring crops decreases and winter crops could become more important, as they can better use winter precipitation and are earlier ready for harvest before the onset of summer drought.

Experiments with winter grain legumes were conducted at the University of Natural Resources and Life Sciences, Vienna, since 2010/11 in Groß-Enzersdorf, east of Vienna

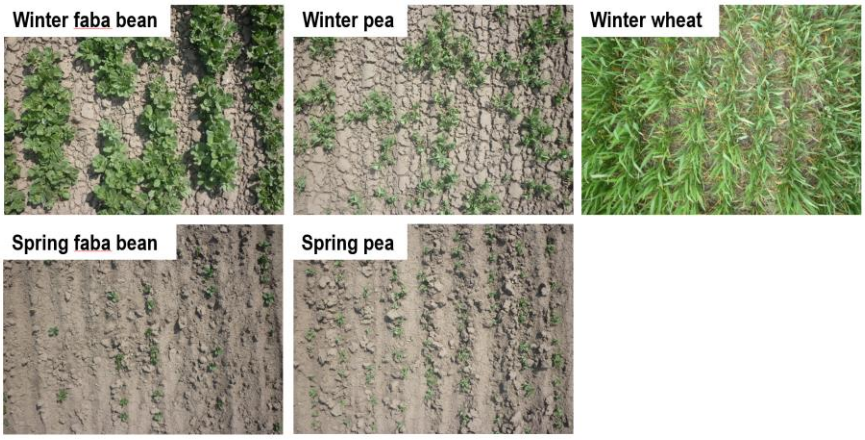

Figure 1. Winter grain legumes cover the soil in spring faster than spring grain legumes (picture taken on April 13th, 2015).

Figure 2. From left to right: winter faba bean, spring faba bean, winter oat, spring pea, and winter pea on May 19th, 2015 (above) or July 9th, 2015 (below).

at the edge of the Marchfeld plain, which is an important crop production region in the north-western part of the Pannonian Basin (4, 5). Winter grain legumes showed since the start of our experiments generally a good overwintering capacity. A total loss of winter faba bean was observed just in one year due to severe late frost. Results are shown of a two year experiment (2013/14 and 2014/15) in which the winter pea varieties Aviron, Cherokee, Curling, Enduro, Isard and James were compared to spring pea Astronaute and the winter faba bean varieties Diva and Hiverna were compared with the spring faba bean Alexia. Unfertilized winter wheat Xenos was used as reference crop for calculating dinitrogen fixation according to the extended difference method (6). Therefore, both the difference in N uptake in the above-ground biomass and the difference in the soil nitrate content (NO_3-N; 0-90 cm soil depth) of the legume and the reference crop at harvest were added. Mean values over years and varieties are shown for winter and spring crops. Winter grain legumes cover the soil much faster in spring than spring grain legumes which is beneficial for suppression of weeds. Anyhow, the soil coverage of winter grain legumes in winter and early spring is lower than that of winter wheat (Figure 1).

Spring grain legumes are often just sown late when the heavy soils are dried off. Whereas winter grain legumes can start growth early in spring using thereby the moist conditions for biomass production. Figure 2 is showing the crops stands on two dates in 2015. A sufficient and continuous water supply is especially important for grain legumes, mainly during flowering, otherwise they react with flower shedding and reduced pod set. As winter grain legumes are considerably ahead in their crop development compared to spring grain legumes, important growth stages like flowering, seed filling and ripening start earlier, last much longer and finish earlier before the onset of summer drought. In eastern Austria, winter grain legumes start flowering around the beginning of May, about three weeks ahead of spring grain legumes. And winter grain legumes are ripe one or two weeks before spring grain legumes.

The mean grain yield over both years and all varieties were for winter pea 4.45 t ha^{-1} and for winter faba bean 3.06 t ha^{-1}. Winter peas could thereby achieve the double amount of grain yield compared to the spring pea and the yield of winter faba beans was about 50% higher than that of the spring faba bean (Figure 3A). Also crop residue yields of winter grain legumes were higher than those of the spring grain legumes (Figure 3B).

Highest N concentrations in the grain occurred for winter faba bean (with 4.7%), followed by spring faba bean. Spring pea had higher grain N concentration than winter pea (Figure 3C). The N concentration of pea residues was higher than those of faba bean, in both cases with higher values on winter than on spring forms (Figure 3D).

The grain N yields and residue N yields of spring grain legumes were just as high as those of winter wheat (grain: 91 kg N ha^{-1}, residues: 32 kg N ha^{-1}). Compared to the cereals, the N yields of winter pea were with 174 kg N ha^{-1} in the grain and 72 kg N ha^{-1} in the residues by about double as high and for winter faba bean with 145 kg N ha^{-1} in the grain and 52 kg N ha^{-1} in the residues by about 60% higher (Figures 3E, F, G).

The content of soil nitrate at harvest at a depth of 0-90 cm was for winter pea at 56 kg NO_3-N ha^{-1} and for winter faba bean at 51 kg NO_3-N ha^{-1} being about three times higher than for winter wheat. Nitrogen contents of spring grain legumes were slightly higher than those of winter grain legumes (Figure 3H). Winter pea showed the highest dinitrogen fixation with 166 kg N ha^{-1} followed by winter faba bean with 102 kg N ha^{-1}. The dinitrogen fixation of spring grain legumes was 43 kg N ha^{-1} for spring pea and 20 kg N ha^{-1} for spring faba bean what were considerably below their winter forms (Figure 3I).

The N balance was calculated as the difference between dinitrogen fixation and N removal with grain. Winter wheat had the lowest N balance with -91 kg N ha^{-1} and winter pea the highest with -8 kg N ha^{-1}. All grain legumes had a negative N balance (Figure 3J). Consequently, although winter grain legumes had a high dinitrogen fixation, the simultaneous high grain yields resulted in a high N removal with grain. Spring grain legumes had both a low dinitrogen fixation and low grain yields, presenting a negative N balance.

Conclusion

The winter forms of pea and faba bean had in a two-year field experiment in eastern Austria, higher grain yield, higher grain N yields and higher dinitrogen fixation than their corresponding spring forms. The content of soil nitrate at harvest was similar for winter and spring grain legumes. Although, the pre-crop effect of winter grain legumes might be stronger than that of spring forms, much more N remains on the field due to the higher amount of residues.

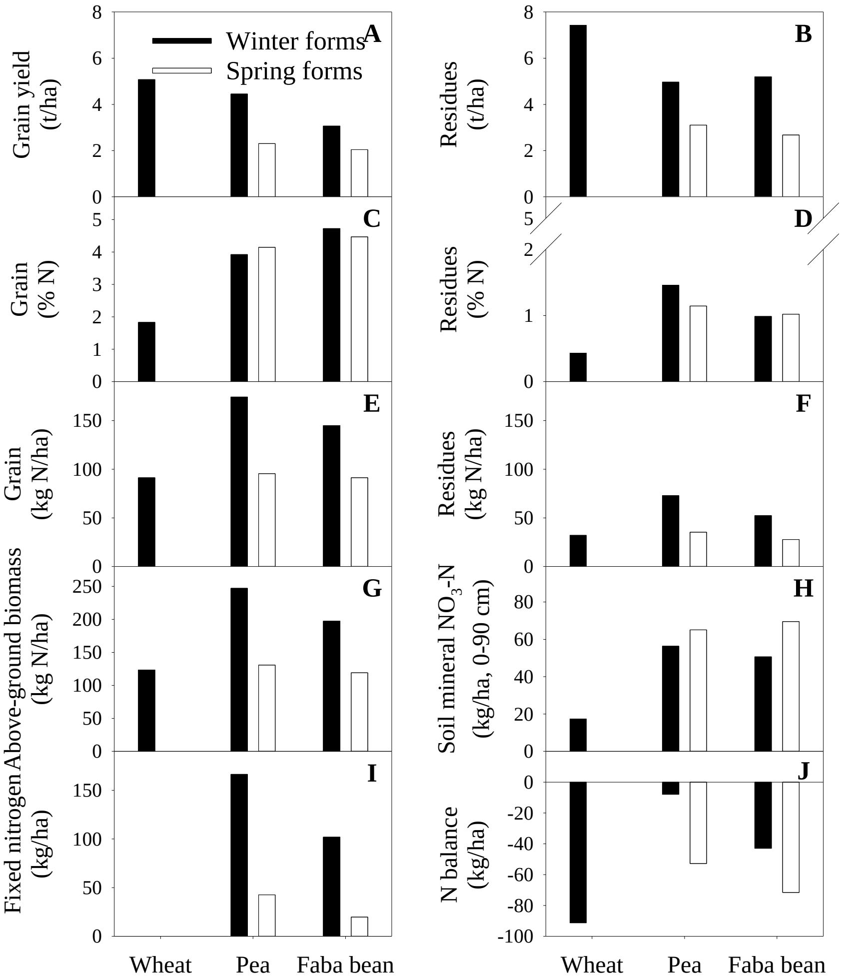

Figure 3. Yields, N concentrations, N yields, soil mineral nitrate at harvest (0-90 cm), dinitrogen fixation and N balance of winter and spring forms of pea and faba bean in comparison to winter wheat.

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Resource acquisition and ecosystem services provided by bi-specific cover crop mixtures

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Abstract: Multi-service cover crops are used to provide ecosystem services, particularly for nitrogen management, such as “nitrate catching” and "green manuring" effects. Sowing cover crop mixtures including legumes and non-legumes have the advantage of combining the provision of both services related to N management thanks to phenomena of niche complementarity and/or facilitation in the capture of abiotic resources. When complementarities are optimized, these species mixtures can achieve both effects similarly to those provided by the average of mono specific cover crops, especially for nitrate catching. In addition, the complementarity for the access to light thanks to species having different aerial architectures and contrasted temporal complementarities enable them to obtain services in relay, in particular in the case of the longest fallow periods over mid-Spring. However, in order to achieve the targeted services, attention must be paid to limit competition between species in particular during early stages.

Key words: Catch crop, green manure, nitrogen, intercropping, complementarity, facilitation, competition

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Introduction

Multiservice cover crops (MSCC) are sown between the harvest of a main cash crop and the sowing of the next cash crop (fallow period) to provide various ecosystem services, such as reducing nitrogen losses through nitrate leaching – the "nitrate catching" effect and supplying mineral nitrogen to the next cash crop – the "green manuring" effect. In addition, these MSCC can also protect the soil against erosion, explaining why they are so called “cover crops” (e.g. 1).

The effects of cover crops have been widely studied in the literature as monospecific crops and these effects seem to be contrasted according to the species sown (2, 3). In particular, although all species can produce ecosystem services related to nitrogen management, legume species are more efficient than other species in providing a "green manuring" effect due to their ability to acquire nitrogen through symbiotic fixation of atmospheric N_2 (e.g. 4). Because of this property, legumes are able to acquire a large amount of nitrogen, without N-fertilizer or in low soil N availability. With a low C/N ratio (high N concentration), legumes favour rapid mineralization of this nitrogen after their termination and incorporation into the soil (5, 6). On the contrary, species other than legumes, particularly crucifers, are generally more effective in catching residual mineral nitrogen in the soil – the “nitrate catching” effect – and thus can strongly reduce nitrate leaching and thus enable to mitigate aquifer pollution (7).

An interesting way of simultaneously combining the two "nitrate catching" and "green manuring" ecosystem services is to sow species mixtures including legumes and non-legumes plants (e.g. 4, 8 - 10). This practice can be seen as a form of ecological and eco-functional intensification for sustainable agricultural production (11, 12) whose principle is based on the complementary use of resources between species.

To be effective, species must not strongly compete for the same resource niche to reach complementarity as it is the case for nitrogen in legume/non-legume mixtures (13 - 16). Interactions between species are complex and evolve during the crop cycle (17). Several studies carried out on cereal–legume cash mixtures have focused on the dynamics of interactions between species and have made it possible to illustrate this complementarity resources use, whether it is a question of light interception or nutrient acquisition which ultimately explains the performance of these mixtures, particularly in terms of yield (14, 18 - 21).

In the case of MSCC whose growth duration is reduced to a few months (from 2 to 6 months), the study of these interspecific interactions in dynamics allows us to refine our understanding to ultimately optimise the species mixture according to the targeted

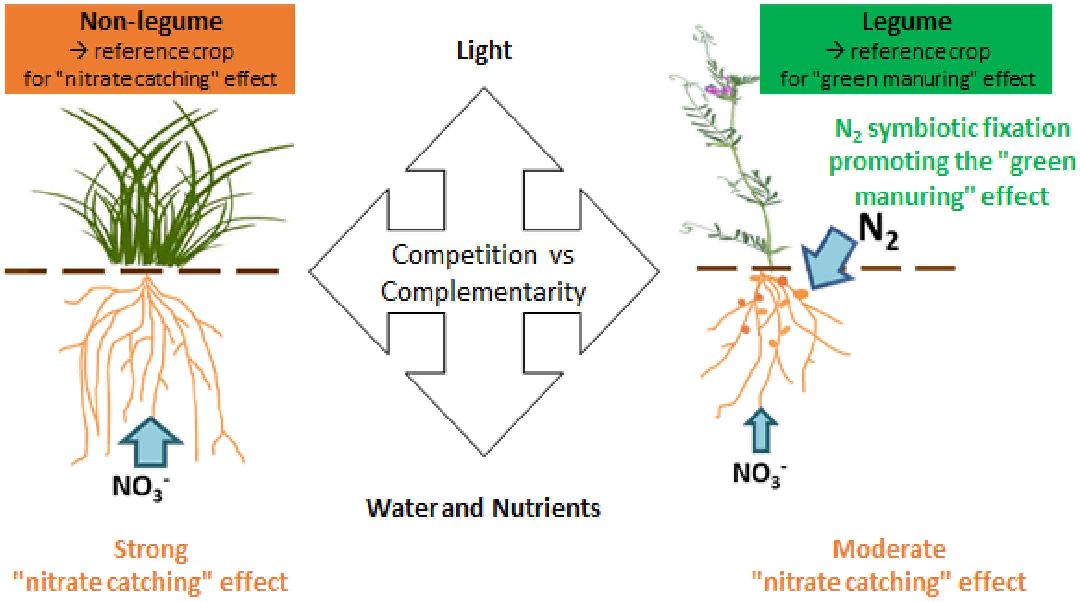

Figure 1. Diagram of interactions between species in relation to the production of nitrogen management services.

services. Indeed, these services, notably "nitrate catching" and "green manuring", will depend, among other things, on the growth duration, the date of termination of the cover crops and the selected species (5). The objective of this paper is to present what is known about the functioning of MSCC mixtures in order to better understand and predict their behaviour and performance for the production of the targeted ecosystem services.

Combining nitrogen management services

Combining nitrogen management services provided by bi-specific cover crop mixtures is possible thanks to complementary resource acquisition illustrated in Figure 1. In these mixtures, the non-legume crop is expected to uptake mineral nitrogen in the soil and thus reduce nitrate leaching (7, 22), whereas the associated legume, although uptaking a part of soil mineral N, will mainly fix N_2 from the air and then would produce a "green manuring" effect by increasing the concentration and content of N in plants (23, 24).

Several studies have shown that MSCC mixtures with a legume (e.g. gramineous-legume or crucifer-legume mixtures) increase biomass production but also provide ecosystem services comparable or even higher than the best pure crops, particularly with regard to nitrogen management, allowing to provide a good compromise of services higher than the average of the two pure crops (e.g. 4, 8, 25).

In fact, certain legume–non-legume MSCC mixtures make it possible to provide a "green manuring" effect close to that of pure non-legume crops. For example, according to Ranells and Wagger (26), a mixture of rye with hairy vetch would make it possible to restore a quantity of nitrogen close to that of a pure hairy vetch crop (132 kg N ha^{-1} for the mixture 8 weeks after the termination of the cover crop, against 108 kg N ha^{-1} for vetch alone and 41 kg N ha^{-1} for rye alone). Indeed, the introduction of a legume in the mixture decreases the C/N ratio compared to pure non-legume crop, especially for ryegrass–clover, rye–hairy vetch or rye–clover mixtures (8, 10, 26, 27).

Reducing C/N ratio leads to a faster mineralisation of the residues and therefore to a faster and higher quantity of nitrogen available for the following crop. Indeed, pure non-legume crops present a risk of nitrogen pre-emption due to their higher C/N ratio, which limits the net nitrogen mineralisation of the residues. However, the effect on the following crop, especially on its yield, is highly variable and depends on soil and climate conditions, but also on cropping systems and management of the mixture, especially through the date and method of termination (24). Overall, MSCC mixtures combining a legume and a non-legume crop have a neutral or positive impact on the yields of the following crop (28 - 30) whereas pure non-legume crops often have a negative effect on the yields of the following crop (31 - 34).

This type of MSCC mixtures can also be effective in reducing residual mineral nitrogen in the soil (23) and thus the potential leaching of nitrate. These MSCC mixtures can sometimes have the same nitrogen capture ability than pure non-legume, especially in relatively low mineral nitrogen environments. This is particularly the case for mixtures of radish–vetch, radish–pea and barley–hairy vetch (25, 35). Although environmental conditions greatly influence nitrate leaching, in the case of barley–hairy vetch mixtures, the reduction in the amount of N leaching has been demonstrated during the growing cycle but also after canopy termination and incorporation (25). Mixing species with legumes limits the pre-emptive competition for mineral nitrogen, particularly when the winter is dry with low drainage and leaching (36, 37).

Assembly rules for multiservice cover crops mixtures

The dynamic analysis of the performance and interactions between mixed species is intended to help in the choice of species to be mixed according to the growing conditions (soil, climate, length of interbreeding, type of main crop succession). To this end, the results obtained by Tribouillois (38) and Couëdel (39) on various experimental sites have shown that certain bispecific mixtures such as forage shuttle–black lentil or moha–purple vetch can be effective in reducing leaching close to that of pure non-legumes, but they did not always simultaneously produce a "green manuring" effect as high as that produced by pure legumes due to the dominance of the non-legume in the mixture, and vice versa.

No MSCC mixture can simultaneously achieve the maximum level for "nitrate catching" and "green manuring" services provided by pure non-legume and legume species respectively. However, we observed that in species mixtures niche complementarity and facilitation phenomena occurred and thus made it possible to reach compromises between the two services to the extent of at least 80% for each of the two targeted services, even if sown at half density of the pure cover crop (e.g. Italian ryegrass–purple vetch or phacelia–faba beans).

In addition, some species mixtures have shown different behaviours depending on the pedoclimatic sites. Thus, for the same MSCC mixture, inversions of competition between legume and non-legume plants have been observed between sites, which leads to different performances in the compromise between "nitrate catching" and "green manuring" services (4). The choice of species to be combined must therefore be reasoned according to: 1) the type of soil, which can be more or less draining, and 2) the climate, particularly the level of rainfall, which may or may not favour drainage, but also the temperatures, which may, for example, limit the development of species or destroy those that are sensitive to frost.

Finally, our results show that the choice of species mixtures must also be reasoned according to the fallow management method and in particular the date of termination of the cover crops. From an operational point of view, the following key results can be retained to design bispecific MSCC mixtures, here with examples for Southern France:

In the case of a short fallow period with early termination (between Mid-October to Early-November) followed by sowing of a winter crop or before deep tillage (in the case of clay soils), both species must develop very rapidly to avoid a strong dominance of one species over the other. In this case, a mixture of forage turnip–faba bean or white mustard–purple vetch can be used. It should be noted that the choice of crucifer could have possible allelopathic effects on the legume even if it has not been fully demonstrated yet (40).

In the case of a long fallow period with termination before winter (by End-December), preference should be given to a mixture composed of species that develop sufficiently rapidly but not necessarily synchronously. In this case, the slower growing species should not be sensitive to frost and low temperatures in order to be able to maintain a "nitrate catching" effect and increase the "green manuring" effect throughout the autumn. In this case, a mixture of ethiopian mustard–common vetch could be planted, for example.

In the case of a long fallow period with termination at the beginning of spring, it is desirable to provide both nitrogen management services while maintaining a vegetative soil cover to avoid soil erosion or structure degradation. In this case, species must be resistant to winter conditions (low senescence and/or good frost tolerance), i.e. a mixture of ryegrass–red clover can be chosen. One may also want to have a succession of these N services thanks to a temporal complementarity for access to resources, starting with an efficient "nitrate catching" effect at the beginning of the cycle followed by a "green manuring" effect in a second stage. In this case, a mixture associating a non-legume plant with early development in autumn can be sown to enhance the nitrate catching very early

Figure 2: Example of the evolution of the moha–clover mixture to provide "relay" ecosystem services through early moha development and then maintenance of winter cover with frost-resistant clover. Photographs taken: a) 4th October 2012 and b) 8th January 2013.

during autumn. This non-legume plant should be very sensitive to frost (from -1 or -2°C) to be destroyed naturally as soon as the first frost occurs, leaving the place for the legume to grow later. This is for example the case for tropical crops such as moha, fodder sorghum, nyger or buckwheat. The latter must therefore be tolerant to frost and winter conditions with a significant capacity for growth and nitrogen acquisition in late autumn and during winter in order to provide a later "green manuring" effect while maintaining soil protection (38). This behaviour was observed, for example, in the case of moha–clover and sorghum–clover mixtures (Figure 2).

Conclusion

The performance of MSCC mixtures depends on the complementarity between species, particularly with regard to the capture of resources. The dominance of one species in relation to another will determine the level of ecosystem services produced and their temporal provision. However, when complementarities are optimised, MSCC mixtures combining legumes and non-legumes crops can achieve performances close to those provided by the best pure crop and always higher than the average of the corresponding pure crops in terms of "nitrate catching" and "green manuring" services.

This effectiveness of the MSCC mixtures in combining the two effects is due to niche complementarity and/or facilitation in the capture of abiotic resources. Similarly, complementarity in terms of access to light thanks to species with different aerial architectures and contrasting temporal growth dynamics makes it possible to obtain effective MSCC mixtures to provide services in "relay" (temporal complementarity), particularly in the case of long fallow period. However, to obtain the expected effects, attention must be paid to limit competition between species for the same niche resources.

For this purpose, there are many species of MSCC that are contrasted in terms of growth capacity, frost sensitivity or maintenance of winter growth, which make the choice of the species to be mixed difficult but nevertheless essential for the success of the cover crop. Another difficulty is that the intensity of ecosystem services provided varies according to the date of termination and the pedoclimate context, requiring trade-offs between the targeted services. MSCC mixtures may have other interests than those related to nitrogen, such as improving soil protection through longer and faster soil cover, improving sulphur management, storing carbon and reducing greenhouse gas emissions (41). Finally, from a practical point of view, MSCC mixtures reduce the risk of bad sowing thanks to a diversity of sensitivities to sowing conditions. Thus these mixtures represent a form of security for achieving the targeted services (36, 40).

The choice of species must be adapted to the pedoclimate and the cropping system. In a situation with high residual mineral nitrogen in soil at harvest, or after a grain legume, it will be preferable to choose a mixture favouring the "nitrate catching" effect or a pure non-legume crop, in particular if the soil is filtering and/or the winter climate is usually very rainy. On the other hand, in a situation of a low residual mineral nitrogen, with incorporation of crop residues, and moreover in conditions of poor drainage, a mixture favouring the "green manuring" effect is recommended to avoid a nitrogen pre-emption effect for the next cash crop.

There are many factors influencing the performance of MSCC mixtures. Among them, the choice of species, the number of species to be combined and their seeding densities are probably essential factors that need to be studied further. Finally, the effects of MSCC mixtures have yet to be studied for many services, which opens up a vast field of research to be explored further. In particular, this shows the limits of classical experimentation and suggests the possibilities offered by crop models to explore this rich diversity of practices and services.

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Forage pea and annual ryegrass mixtures for soil conservation and forage production

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Abstract: This study was carried out in order to determine hay yield and some quality parameter of yield and the best mixture ratio in randomized block design with three replications throughout 2017-2018 growing season in Çarşamba/Samsun conditions. The seeds were sown at November 16th, 2017 and harvest of lower pods of pea plants at May 1st, 2018. Cultivar "Caramba" of annual ryegrass (*Lolium multiflorum* var. *westervoldicum* L.) (ARG), leafed "Gölyazı" cultivar of forage pea (*Pisum arvense* L.) (LFP) and semi-leafless forage pea cultivar "Kirazlı" (SLFP) were used in the study. Besides the solely plots of the cultivars, different mixture ratios of annual ryegrass with forage pea cultivars were experimented. Hay yields of the treatments ranged between 17.47 t ha^{-1} (60% SLFP+40% ARG) and 6.61 t ha^{-1} (100% ARG). The highest crude protein ratio was 17.04% for 80% LFP+20% ARG plots. While ADF ratio of hays varied between 28% (100% ARG) and 38% (100% SLFP), NDF ratios ranged from 43.05% (20% LFP + 80%ARG) to 50.40% (%100 SLFP).

Key words: forage pea, annual ryegrass, mixtures, soil, forage

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Introduction

Turkey has not achieved yet a satisfying level of animal products production. One of the main problems is that it could not supply yet an adequate high quality and cheap feed for livestock. The farms should be able to produce their own roughage for a sustainable and profitable animal husbandry. To increase forage cultivation, forage crops should be added into crop rotation systems as main crops and/or double crop. The Central Black Sea and other coastal regions of Turkey are very convenient for annual winter forage catch (or cover) crop production. In addition to the production of high quality forage, these systems supply benefits such as prevention of the soil erosion, suppression of weeds, and increase organic fragment of soil. Forage catch crops should consist of legume + grass mixtures. Thus, more balanced forage could be obtained regarding the protein and carbohydrate contents. Examples of forage crops that can be used as winter forage catch crops are common vetch, Hungarian vetch, forage pea, cool season cereals and annual ryegrass.

Pea is an important annual legume grown and consumed extensively both for human food and animal feed. Forage peas are widely grown for hay, pasturage or silage production either alone or mixed with cereals (1). Both seeds and forages of pea are rich in protein and mineral content (2). Forage pea is a very suitable crop for annual crop rotation because it provides biological nitrogen for the plants sown after it (3). There are two main leaf types in field pea. One has normal leaves; the second type is the semi-leafless type that has modified leaflets reduced to tendrils with vine lengths of two to four feet (4).

One of the most important forage crops is annual ryegrass which is a cool-season grass that is suitable for quality herbage production on account of its rich protein, minerals, and water-soluble carbohydrate content (5, 6). In recent years, one of the cultivars of annual ryegrass, 'Caramba', has quite well adapted to Turkey's climate and soil conditions (7, 8), being recognized as potential roughage for ruminant animals (9, 10).

This study was carried out to determine hay yield and some quality parameters of different forage pea and annual ryegrass mixtures.

Results and Discussion

With regard to the hay yields, there were highly significant differences among treatments. Average hay yields of the treatments varied between 6.61 and 17.47 t ha^{-1} and the lowest values were obtained from solely plots. The mixtures containing semileafless cultivar "Kirazlı" at 60%SLFP+40%ARG (17.47 t ha^{-1}), 80%SLFP+20%ARG (16.32 t ha^{-1}) and 70%SLFP+30%ARG (15.96 t ha^{-1}) and containing leafy forage pea cultivar

Table 1. Average hay yields of the treatments and crude protein ADF and NDF ratios of hay.

Treatments	Hay Yields (kg ha^{-1})			CP (%)	ADF (%)	NDF (%)
	Forage Pea	Annual Rye Grass	Total			
100% LFP	8338	--	8338 bc	16.74 ab	33.74 b	46.33 abc
100% SLFP	8076	--	8076 bc	16.49 abc	37.67 a	50.40 a
100% ARG	--	6614	6614 c	11.49 f	28.35 d	44.59 bc
20% LFP +80%ARG	5482	7736	13218 ab	17.04 a	30.92 bcd	43.23 c
30% LFP +70% ARG	8242	6509	14751 a	14.72 a-e	33.83 b	48.06 ab
40% LFP +60%ARG	7903	4756	12659 ab	15.11 a-d	33.17 bc	46.82 abc
50% LFP +50% ARG	10530	4816	15346 a	14.58 a-e	31.00 bcd	44.55 bc
60% LFP +40% ARG	10296	4409	14705 a	14.32 b-e	30.02 cd	44.24 bc
70% LFP +30%ARG	11153	3442	14595 a	12.45 ef	29.70 cd	45.05 bc
80% LFP +20%ARG	12060	3802	15862 a	13.36 def	29.68 cd	43.05 c
20% SLFP +80%ARG	4309	7030	11339 abc	14.10 c-e	32.31 bc	45.39 bc
30%SLFP +70% ARG	4718	7758	12476 abc	15.15 a-d	31.92 bc	44.82 bc
40% SLFP +60% ARG	7623	6117	13740 ab	14.99 a-e	31.71 bcd	44.96 bc
50% SLFP +50% ARG	5803	6217	12020 abc	15.09 a-d	31.84 bcd	46.10 bc
60% SLFP +40% ARG	10666	6799	17465 a	13.11 def	32.42 bc	48.25 ab
70% SLFP +30% ARG	10493	5468	15961 a	12.69 def	31.22 bcd	45.77 bc
80% SLFP +20% ARG	12561	3762	16323 a	13.83 def	30.94 bcd	46.04 bc
Average	8645	5616	13147	14.42	31.79	45.74

***No significant differences among figures showing the same letter in the same column (P<0.05)**

Figure 1. Field pea in the experiment.

"Gölyazı" at 80%LFP+20%ARG (15.86 t ha^{-1}) and 50%LFP+50%ARG (15.35 t ha^{-1}) gave higher hay yields (Table 1).

Consider crude protein, ADF and NDF ratios of the hay, there were significant differences amongst treatments. The highest crude protein ratio was determined to 80%LFP+20%ARG mixture, but many other treatments are in the same group. As increasing forage pea ratio in the mixture, crude protein ratio increased and the mixture containing 50% or more forage pea differentiated from the others, statistically. ADF ratios of the treatments varied between 37.67% and 28.35%. While the highest ADF ratio was determined in semileafless forage pea alone, the lowest was obtained from annual ryegrass alone. When we evaluate the forages based on the American Forage and Grassland Council (AFGC) standards in what relates to ADF and NDF contents,

Figure 2. ARG + FP mixtures, Left: ARG + LFP, Right: ARG + SLFP.

except for 100% SLFP, all samples were in prime class. NDF ratios determined in this study varied between 43.05 – 50.40% (20%LFP+80%ARG - 100% SLFP respectively) (Table 1).

Conclusion

Considering forage yield and quality of the hay, both leafy and semileafless forage pea cultivars are very suitable for mild and humid Samsun climatic conditions. To obtain higher quality and yields, late (slowly growing) forage pea cultivar should be chosen to make the mixture with annual ryegrass. When evaluating forage yield and quality parameters, the 60% SLFP+40%ARG, 80%LFP+20ARG or 50%LFP+50%ARG mixtures might be recommended to Samsun and similar ecological conditions. Nevertheless, at least a second year of this study should be carried out to be able to validate this recommendation.

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Vetch (*Vicia* spp) for forage, green manure, and grain production in Mediterranean areas

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Abstract: Spain is probably the country with the greatest area of vetch production in Europe, which increased for forage production and declined for grain. This manuscript is a short summary of the uses of vetches in Spanish agriculture in recent times. Currently the list of commercial varieties in Spain includes 24 types of common vetch (*Vicia sativa* L.) and 5 of hairy vetch (*Vicia villosa* Roth). Vetches could be used as forage under both rainfed and irrigated conditions, although dryland areas are best suited for grain production.

Key words: common vetch, hairy vetch, forage, cover crops, grain

Introduction

Legumes are essential components of many Mediterranean agricultural systems, where climate is normally semiarid, with high solar radiation and low yearly average precipitation. Concretely in Spain, forage vetches (*Vicia spp*) are some of those most grown (1, 2). Vetches are commonly grown in combination with winter cereals, such as oats, for forage production. This cropping system is particularly common in rainfed dry land areas, with little risk of low winter temperatures (-1 to -5 ºC) (1, 3, 4). Nowadays, many seed production companies include vetches in their seed formulations for forage production.

The agri-environmental measures outlined in the European Union's most recent CAP (Common Agricultural Policy) have favoured an increase in the use of vetches, whether for green manure, or as cover and catch crops, particularly in field crop production. The use of vetches for green manure, or as cover crop, can also be found between rows in some fruit-tree systems.

Probably, because of the CAP directives, the area of vetches crops dedicated to forage production in Spain has increased from around 80,000 ha in 2000 to about 143,000 ha in 2020. On the other hand, the area of vetches intended for grain production fell from about 191,000 ha in 2000 to 103,000 ha in 2020 (5). Therefore, current area of vetch production is around 243,000 ha, showing either the importance of CAP policies or the limited economic benefits of growing vetches for grain. At the time of writing, Spain is probably the country with the greatest area of vetch production in Europe (4).

This paper provides a short summary of the uses of vetches in Spanish agriculture in recent times.

Varieties and their production

The List of Commercial Varieties in Spain includes 24 types of common vetch (*Vicia sativa* L.) and 5 of hairy vetch (*Vicia villosa* Roth) (6). However, farmers do not usually ask for a particular variety; they just request vetch. This is probably due to their limited knowledge of the comparative characteristics of its different varieties.

Although varietal selection is an important aspect to achieve profitable vetch yields, information about the forage value and grain yields of vetch varieties remains limited (7 - 9). The results from a particular trial are presented here as an example of variety classification and yield variability. Sixteen of the best-known varieties of common vetch grown in Spain were compared (Tables 1 and 2) for two different growing seasons, at two different locations (Foradada and Gimenells) in Catalonia (northeast Spain). One location had rainfed, dryland conditions, while the other was under irrigation. The long-term average annual temperature and rainfall values for the two locations were 14 ºC and 14.6 ºC and 345 and 450 mm, respectively. The particularities of these trials

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Table 1. Classification of the varieties based on number of days to flowering.

Cycle	Varieties	Days to flowering	
		Foradada	Gimenells
Early	Albaflor, Alcaraz, Armantes, Borda, Hifa, Prontivesa	150-160	125-135
Medium	Aitana, Aneto, Gravesa, Neska, Serva, Urgelba	161-174	136-147
Late	Acis Reina, Topaze, Libia, Filón	175 -192	147-152

are provided in Ballesta *et al.* (7). A classification of the different varieties, based on the time of the earliest flowering, is presented in Table 1.

The varieties studied grouped into three different cycles, based on their initial flowering dates (between April and May) (Table 1). The flowering cycles and their classification coincided with those reported by Lozano *et al.* (10) in a similar region. The average forage and grain production and the crude protein (CP) contents of vetches used for grain and forage are presented in Table 2.

The average dry matter (DM) forage yield was of 8338 kg/ha under irrigated conditions and 5883 kg/ha in dryland areas, with average crude protein contents of 16.1% and 16.0%, respectively. However, there was a wide range of DM yields among varieties under rainfed conditions from 2680 kg DM/ha to 7533 kg DM/ha, without any significant differences among them for irrigated conditions. This could have been due to the plants having been left to grow for too long or because of the prostate growth habit of vetches, which may have resulted in damage to parts of plants that were in contact with the soil.

Figure 1. Field experiment with different varieties of vetch at Gimenells with irrigation

The forage DM yields varied depending on each year weather conditions, particularly in the rainfed location. The DM yields achieved were similar to those reported for other areas of Spain. As an example, in a variety-trial including 13 varieties conducted in Aragón (north-central Spain), Lozano *et al.* (10) obtained an average 3-year forage production of 4515 kg DM/ha, ranging from 3563 to 5375 kg DM/ha. In another trial, with 15 varieties conducted in Castilla y León (north-west Spain) under rainfed conditions, Provedo and Caminero (9) obtained average forage yields ranging from 2766 (1299-3685) kg DM/ha at one location to 4741 (2973-5992) kg DM/ha at another.

In the case of grain production, yields also depended on the season. Aneto, Prontivesa, Neska and Serva were the highest yielding varieties at Foradada (rainfed location), yielding between 1071 to 1342 kg/ha, whereas Borda, Serva, Prontivesa and Topaze were amongst the best cultivars, yielding between 1048 to 1220 kg/ha, at Gimenells (irrigation). The CP content varied from 30% to 33%. Better grain yields were obtained under rainfed conditions than under irrigation. This was possibly because there is often too much vegetative growth under irrigation and because of the prostate growth habit of growth of vetches, which could have spoiled some parts of the plants and complicated grain harvesting. For this reason, vetches grown for grain are normally cultivated in rainfed areas and as part of a mixture of cereals, with a low vetch seeding density.

The overall result showed that vetches can yield a good amount of forage of good quality under both rainfed and irrigated conditions, and that rainfed areas are better suited to grain production.

Mixtures of vetches with cereals

There are many reports, from different countries (2, 11 - 13) showing that mixtures of vetches with different cereals produce higher forage yields than when vetches are grown alone. Furthermore, cereals grown alone normally produce more forage than when mixed with vetches. Even so, the main point is that vetches increase both the CP and the forage quality of the mixture. Mixtures of legumes with cereals are expected to offer advantages over pure stands in terms of forage yield and quality. In cases of vetch–cereal intercropping, cereals provide structural support for vetch growth, improving light absorption and allowing mechanical harvesting (12). Working under

Table 2. Forage dry mater (DM) and grain yield and crude protein (CP) content at a rainfed and an irrigated locations. Average values for 2000 and 2001 seasons.

Variety	Rainfed				Irrigated			
	DM yield (kg/ha)	CP (%)	Yield (kg/ha)	CP (%)	DM yield (kg/ha)	CP (%)	Yield (kg/ha)	CP (%)
Acis Reina	5144	16.6	520	31.49	8278	16.8	579	30.05
Aitana	4379	17.8	756	33.41	7104	16.5	699	33.10
Albaflor	5480	15.2	1010	29.66	7920	15.7	987	28.79
Alcaraz	3081	17.0	501	31.73	-	-	507	27.19
Aneto	7533	16.3	1342	31.82	10135	16.8	646	32.57
Armantes	5172	16.3	1022	28.99	8084	16.6	891	29.12
Borda	5161	15.7	900	31.52	9769	14.9	1220	30.54
Filón	5556	16.0	965	32.50	8471	15.4	692	32.01
Gravesa	3236	16.2	854	32.17	7634	16.5	755	31.83
Hifa	2680	16.6	424	30.98	-	-	808	30.17
Libia	6174	16.4	945	31.64	6443	15.2	561	31.72
Neska	7098	13.9	1120	33.30	6955	16.3	723	29.94
Prontivesa	6597	16.3	1287	28.91	7900	16.3	1052	27.54
Serva	4313	15.4	1071	30.66	8759	16.9	1099	30.72
Topaze	6530	15.8	983	33.84	8793	15.2	1048	25.19
Urgelba	6361	15.6	980	34.39	10471	16.1	1011	31.18
Average	5883	16.2	900	31.57	8338	16.1	840	30.48
L S D	2356	3.08	273	2.59	4160	2.65	353	6.24
CV (%)	34.1	13.5	24.6	3.4	36.8	10.1	34.4	7.8
Significance	0.01	NS	0.01	0.01	N S	NS	0.01	NS

rainfed conditions in central Spain, Caballero *et al.* (2) found that mixed crops produced 34% more dry matter than monocrops of vetch, but 57% less than monocrops of oats. The DM yields of mixed crops were not affected by the seeding rate of vetch.

Roberts *et al.* (11), working with a mixture of vetches with cereals, in Illinois (USA), showed that, under their conditions, wheat (*Triticum aestivum* L.) grown in association with hairy vetch had a greater forage quality potential than that grown alone. The DM yield decreased with increased vetch seeding rates. Crude protein production increased by an average of 46.8% in 1984 and 22.9% in 1985, as vetch seeding rates increased from 0 to 162 plants/m^2. Crude protein was primarily obtained from the vetch fraction, which contained twice as much protein as the wheat fraction in both years.

Lithourgidis *et al.* (8), working in Thessaloniki (Greece), under rainfed conditions, obtained their greatest DM yields with monocrops of wheat and barley. The lowest yield was obtained with common vetch as a monocrop. Intercrops produced about 13–30% more DM than common vetch grown monocrop, but 12–23% less than cereal monocrops. The quality components suggested the advantage of growing common vetch as a monocrop, followed by its use as an intercrop, combined with barley at a seeding ratio of 65:35. The latter had a higher CP than both the monocrop of cereals and the other intercrops.

Yilmaz *et al.* (13), working in Mediterranean areas of Turkey with high rainfall (1000-1100 mm), found that when combined crops of vetch and cereals were compared to pure stands of vetches, the increases in yield ranged from 30.4% to 74.6%. Furthermore, higher ratios of vetch in such mixtures resulted in greater digestible DM values. Additionally, in all the mixed crops analysed, any increase in the vetch ratio resulted in a higher crude protein yield.

Vetches as catch crops for double cropping systems

Vetches can be good companion crops in double cropping systems mixed with grasses for forage. In Mediterranean environments, experiments were carried out using vetch mixed with oats, in double cropping systems (winter crops-maize) with different harvest dates for winter crops. The average DM productions of these mixtures were 5.8 Mg/ha for the April crop (which was well-suited for double cropping with maize) and 8.1 Mg/ha for the May harvest. CPs were 19.7 Mg/ha and 12.6 Mg/ha, respectively. This showed the good potential that vetches offer as companion crops for good quality forage (10). In other areas of northern Spain (Galicia) with mild winters and an Atlantic-type climate, pure crops of hairy vetch, which were seeded at the end of October and harvested in either April or May, produced average yields of 1.6 Mg DM/ha and 3.2 Mg DM/ha, respectively. These

Figure 2. Vetches turned under for green manure in northern Spain.

Figure 3. Field of white flowered vetches with cereals.

increased to 2.3 Mg DM/ha and 4.2 Mg DM/ha for the same treatments at a second location with higher spring temperatures. In those conditions, date of seeding in autumn had a fundamental influence on obtaining good forage yields (13).

Vetches as cover crops

Legume cover crops have long been promoted for their ability to sequester C in soils, reduce erosion, fix atmospheric nitrogen, reduce nitrate leaching, and improve soil health.

In recent years, several publications have discussed the use of vetches in Spain as a cover crop, studying several of the aspects mentioned above. Salmerón *et al.* (15) used vetches as a cover crop to evaluate the reduction of nitrate leaching after a maize crop. Using drainage lysimeters, they found that cover crops were able to reduce N leaching by 38%, while maintaining a similar level of maize N uptake to fallow treatments. One legume cover crop (common vetch), respectively reduced N leaching by 33, 32, and 49% in three soils types, in comparison with fallow-maize strategies. They also found that growing maize after using vetch as a cover crop made it possible to reduce the rate of N fertilizer application by 22%, as a result of taking advantage of N input from the vetch biological fixation of N_2.

After studying the effects of using several different legume cover crops (peas, common vetch, hairy vetch and a control without cover crops) in the same area, Isla *et al.* (16) concluded that hairy vetch had a lower fixation capacity (48.7%) than peas (63%) or common vetch (68.9%). However, the grain yield of maize planted after the cover crop was not significantly affected by any of the cover crops that were evaluated (17). In a review of the influence of cover crops on climatic change, Kaye and Quemada (12) studied several aspects of the performance of vetches as cover crops. Here they concluded that cover crop adoption should mitigate greenhouse gas-based climate change by ~116 g CO_2 e/m^2/year for non-legumes and by ~135 g CO_2 e/m^2/year for legumes. The main sources of variation in these values are soil C sequestration rates and fertilizer credits for cover crops, both of which should be active areas for future research.

In a study of nitrous oxide (N_2O) emissions conducted under field conditions, Guardia *et al.* (1) found that legume cover crops produced greater N_2O emissions than non-legumes while the cover crops were growing. In contrast, after the cover crops had been removed and maize had been planted, plots with a history of non-legume cover crops tended to have higher N_2O emissions than those with a history of legume cover crops. When analysing cover crop and maize periods, and comparing them with a fallow control, vetch cover crops increased N_2O fluxes by 0.01 g N/m2/year, regardless of incorporation, while barley had only a minor effect on N_2O fluxes (relative to the fallow control).

The final N cycle component to mitigate N_2O emissions requires a reduction in the amount of N fertilizer associated with cover crops. N fertilizer is the single largest source of energy used in agricultural production. In their paper Kaye and Quemada (12), report that maize yields after cover crops are often greater than after fallow. In a Spanish case study, maize yields averaged 850 kg/ha after a vetch cover crop and 300 kg/ha after barley. Fertilizer savings, particularly after legume crops, and selling cover crops as animal feed in years with high biomass, may be seen as additional economic benefits of cover crops.

In a ground cover study that compared the advantages of several different cover crops (barley, rye, triticale, mustard, vetch) grown in central Spain, conducted over two seasons and under rainfed conditions, Ramirez *et al.* (18), found that vetch had reached 96% ground cover by the end of the experiment in the first season, but never exceeded 47% in the second. Vetch had the lowest biomass production of the crops compared. This was probably due to low minimum temperatures and winter precipitation, which would have dramatically affected vetch growth during the second season. Vetch DM yield ranged from 1040 kg DM/ha to 4460 kg DM/ha, for the second and first season, respectively.

The authors concluded that vetch is most suitable for green manure production because it provides N through biological fixation and its residues are easily decomposed (with a low C:N ratio and high residue quality).

Figure 4. Vetches showing their prostrated growth habit and yield potential.

Conclusions

The overall results showed that vetches can provide an interesting amount of good quality forage under both dryland and irrigated conditions, although dryland areas are best suited for grain production.

The use of vetches mixed with cereals can provide a good mixture for forage in double cropping systems. Furthermore, vetches produce good amounts of forage for cover crops, catch crops and green manures.

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Soil health benefits of cover crops in a corn soybean wheat cropping system

Jodie Reisner[1,*], Robert J. Kremer[2], Randy Miles[2]

Abstract: Cover crops including legume species reduce soil and environmental degradation and improve soil health. This study examined soil health effects of cover crops integrated into three different crop management systems on a central Ohio farm. Cover crops integrated with no-till and crop rotation improved selected soil health indicators and are effective as an important sustainable management practice.

Key words: crop rotation, legume cover crop, soil management, soil health indicators

Introduction

Cropping systems management and the presence or absence of cover crops directly influence many physical, chemical, and biological soil properties. Cover crops are grasses, legumes, and forbs planted in mixes or as single species for seasonal vegetative cover (1). Growing cover crops in association with grain crops can assist in reducing risks of soil and environmental degradation. Soil health is the ability of a soil to function within an ecosystem and to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health (2, 3). The research focused on the use of cover crops and a no till crop management system to improve soil health compared to a conventional corn-soybean production system. The study involved an assessment of numerous soil health indicators from surface soils collected at a diversified crop farm in Fairfield County, Ohio. The objectives of this study were to compare soil physical, chemical, and biological indicators across different crop management systems.

Materials and Methods

Site samples were collected in Fairfield County, Ohio U.S on a Cardington-Bennington-Pewamo soil association. The three different field sites sampled were described as conventional, transitional, and progressive cropping management systems (Table 1), and soil samples (n) were collected in November 2013.

All samples were taken at a depth increment of 0 to 7.62 cm. Physical tests included wet aggregate stability (4), and chemical tests included active carbon. Biological testing included phospholipid fatty acid (PLFA) to measure microbial biomass and community composition in soils. The PLFAs were extracted and then esterified into fatty acid methyl esters (FAME) (5). The samples were analyzed using MIDI Sherlock microbial identification system at the Soil Health Assessment Center at the University of Missouri Columbia.

A PROC MIXED module in SAS Software Version 9.3 (SAS 260 Institute Inc. Cary, NC, USA) was used to evaluate the effects of management treatments and landscape. The means and standard errors were completed and compared using Tukey Kramer at the significance level $\alpha = 0.05$. Regression analysis procedures were completed on some correlations for this analysis (6).

Results and Discussion

Cover crops were planted in fall 2009 and were included in the transitional and progressive management systems annually thereafter. At the time of sampling, the transitional field had a diverse cover crop mix including legumes present after a winter wheat grain crop. The progressive field has

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Table 1. Cropping Management System for three fields under study.

Descriptor	Conventional n=24	Transitional n=40	Progressive n=100
Vegetation at Sampling	Corn Residue	Diverse mix of cover crops*	Small Cereal Rye plants
Crop Rotation	Corn grain, soybean	Corn, soybean, winter wheat	Corn, soybean, winter wheat
2013	Corn grain	Winter wheat	Soybean
2012	Unknown not rented	Soybean	Corn
2011	Unknown not rented	Corn grain	Winter wheat
Cover Crop	No cover crops	Mix 1 cover crops	Single species 2009-11 Mix 1 – 2012
Tillage	Disking, field cultivate, plant	No till starting in 2009	No till for since 1971

*** Mix 1 = cereal rye 7.5 kg, oilseed radish 1 kg, Austrian winter peas 10 kg, hairy vetch 4 kg, crimson clover 3 kg**

Table 2. Selected soil health indicators average for the different management systems at a central Ohio farm, 2013.

Soil Health Indicator	Conventional Management	Transitional Management	Progressive Management
WAS %	21.83b	37.78a	41.54a
Active C (mg kg-1)	472.36b	526.96ab	582.56a
Fungi (pmol/g)	1280b	1950a	1250b

WAS = wet aggregate stability, Active C = Active Carbon. Mean values for soil physical properties by management system. Values followed by a different lowercase letter for a given factor were significantly different among treatments (using Tukey's HSD) at α = 0.05.

been in a no-till cropping management system since 1971. Single-species cover crops were included in the rotation in 2009 after each grain crop. Diverse mixes of cover crops were implemented in 2012 and at the time of sampling small cereal rye (*Secale cereale* L.) plants were present (Figure 1). Soil health indicators were impacted by the cover crops (Table 2), while field position did not significantly affect soil health parameters across management systems.

Conclusions

The need for research that combines measurements of these soil health indicators with cropping management systems could aid in understanding physical, chemical, and biological parameters of soil that are affected by combined tillage, crop rotation, and cover crops. For example, when a land manager decides to add wheat to a corn and soybean rotation, more management decisions are needed for inclusion of the wheat crop. Then decisions are needed as to whether a diverse mix of cover crops should be used after wheat or to double crop soybean. If wheat is in the rotation, cereal rye can be challenging as a cover crop due to potential price reductions if cereal rye seed is found in the wheat at time of sale. Summer cover crops after wheat are another opportunity to plant a diverse mix of summer legumes. This is just one example of how soil health

Figure 1. Cover crop mix including legumes and grasses in transitional management system.

discussions need to include crop management decisions.

The results from assessments of soil health properties on three management systems at this central Ohio farm demonstrated the contribution of sustainable agricultural practices such as no-till and cover crops for maintaining soil health and biological activity. Complex interactions in soil need more than a few years to change and manifest themselves; therefore physical, chemical, and biological test indicators are important to allow land managers to periodically assess their soils for soil health improvement.

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RESEARCH

Contributions of cowpea to overall productivity and soil health in the solar corridor crop system

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Abstract: The solar corridor crop system (SCCS) is designed for improved crop productivity by using wide rows (corridors) that promote efficient use of solar radiation and ambient carbon dioxide by maize. Recent field trials in mid-Missouri revealed that intercropped cowpea provided ample vegetative biomass that could supplement protein for livestock grazing maize stover as well as benefiting conservation by reducing soil erosion and supporting soil microbial activity and soil organic matter buildup. Integrating cowpea in the SCCS offers multiple benefits of supplemental grain and forage as well as soil conservation that are not provided by conventional mono-cropping of maize.

Key words: cowpea, intercropping, maize, photosynthesis, soil health

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Introduction

Innovative management systems for improving crop production, minimizing external fertilizer and pesticide inputs, and ensuring environmental quality are needed. Management based on wide-row spacing of tall-stature crops (*i.e.*, maize [*Zea mays* L.]), forming a corridor, provides uniform vertical distribution of incident sunlight available to fully exposed leaves. This solar corridor crop system (SCCS) increases availability of sunlight and carbon dioxide to plants in all rows in the field (1). The SCCS advances the strip intercropping design, which is based on cultivating two or more crops simultaneously in different strips across the field for greater use of resources compared with either of the component crops grown in monoculture (2).

Intercropping methods are similar to the SCCS based on the manipulation of row widths to improve sunlight capture, soil moisture conservation, nutrient uptake, and reduce synthetic chemical use. For example, yields of maize, soybean (*Glycine max* [L.] Merr.) and oats (*Avena sativa* L.) planted in narrow strips were increased by 5% compared with mono-cropped maize in a maize-soybean rotation system (3). Intercropping has potential to be an environmentally sustainable farming practice in the Midwestern U.S. by decreasing nitrate leached via subsurface drainage in addition to other conservation benefits of reduced soil erosion, increased soil organic matter, and enhanced water infiltration compared with typical maize-soybean rotations.

Legume crops integrated into the SCCS promote soil microbial biomass and biodiversity including soil mycorrhizal fungi that associate with numerous crops to enhance nutrient acquisition, disease resistance, and drought tolerance. Legumes in cover crop mixtures are a nitrogen resource for the main crop and minimize chemical fertilizer inputs and reduce potential environmental impacts (4). Intercropped species benefit main crops by

Figure 1. Cowpea cultivars used in the solar corridor crop system. The indeterminant cultivar 'Iron and Clay' at 90 days after planting (left). Note abundant vegetative growth, few pods, and climbing vines on maize. The semi-determinant cultivar 'California Blackeye no. 5' at 65 days after planting (right). Top growth covers corridor floor and plants are in pod-filling stage.

deterring insect pests and suppressing weeds through allelopathy. A key sustainable management practice within the SCCS is increasing crop diversity by using compatible floor crops that act as an important secondary grain or forage crop and promote soil health improvement and conservation.

We evaluated cowpea (*Vigna unguiculata* (L.) Walp.) as a floor crop inter-planted with maize in the SCCS. Cowpea was selected based on its tolerance to moisture and heat stress and shading; high resistance to diseases and insect pests and moderate weed suppression; symbiotic nitrogen-fixing ability and soil conservation benefits including abundant soil surface coverage, relatively deep rooting, and high biomass production (5). Additionally, it is a multi-purpose crop that provides high protein and essential nutrients for livestock either as forage or grain, nutritious pulse grain for human diets, and cover for beneficial arthropods and wildlife, in addition to the soil conservation benefits.

Materials and Methods

Cowpea was grown as the floor crop in the 152-cm corridor provided by the SCCS with maize as the main crop on Mexico silt loam soils (fine, smectitic, mesicVerticEpiaqualfs) in Boone County, Missouri (38°53'48''N, 92°12'24''W) during 2014-2016 and 2019. Soil and crop management procedures were reported previously (6). Soil samples (3.8-cm diam by 10-cm deep cores) and cowpea plants were collected at the early bloom stage. Plants were weighed, dried and subsamples analyzed for tissue nutrient contents; soils were analyzed for active carbon using the permanganate oxidation procedure, water-extractable carbon (WEOC), and soil glucosidase activity as described previously (6, 7).

Results and discussion

Cowpea readily established in the 152-cm corridors of the SCCS with vegetation covering the soil surface within 30 to 45 days after planting (Figure 1). Biomass decreased in the corridor by 35 to 65% relative to a cowpea monoculture but varied based on seasonal conditions (Table 1). The reductions in yield were similar to previous results noted for intercropping cowpea with maize and other crops (5). Production in 2019 was also affected by weed competition. Nitrogen content of cowpea biomass ranged from 3.5% for an indeterminant cover crop cultivar 'Iron and Clay' to 6.0% for a determinant bush-type cultivar 'Ozark Razorback', which potentially contributed 12 to 30 kg ha^{-1} N to soil if biomass remained in the field to supplement the 17 ha^{-1} N from maize residues. Cowpea out-performed in biomass production and N yield compared to mung bean (*Phaseolus aureus* Roxb), a legume floor crop option, or to weeds growing in the corridor (Table 1). Cowpea can be managed for harvest of fresh peas or dry seeds in the SCCS for human or animal use. We harvested 1430 kg ha^{-1} fresh peas in one trial (Table 1); cowpea allowed to mature could be harvested for dry peas manually or mechanically after maize harvest (data not shown). Varietal selection is an important consideration affecting management goals. Some indeterminant varieties such as 'Iron and Clay' aggressively cover the soil surface, mature late (100 days) with few pods, and will vine onto standing maize making mechanical harvest difficult. Semi-determinant (California Blackeyes) or determinant ('Ozark Razorback') are compact and vine less aggressively (Figure 1), mature in 45-60 days, and are more adaptable to either manual or mechanical harvesting after maize.

Cowpea improved selected soil health indicators in each year of evaluation; results were similar across years, only 2016 data are presented (Table 2). Labile soil C fractions, active C and WEOC, in cowpea corridors increased significantly relative to the fallow weedy corridors (Table 2). Labile C is important in supporting an active and diverse soil microbiome that mediates critical biological functions including nutrient cycling, plant growth promotion, and suppression of potential pathogens. Glucosidase activity also increased indicating that biological processes, especially C cycling, was improved when cowpea was included as a floor crop. The improvement in biological processes by cowpea was synergistic with positive effects of maize suggesting that overall soil health in the SCCS was improved when corridors were occupied by a compatible floor crop relative to non-planted corridors.

Conclusions

Legume crops such as cowpea combined with maize in the SCCS contribute positively (synergistically) to improved soil health especially relative to maize monoculture. Cowpea is adaptable to the SCCS and contributes supplemental vegetative residue for soil fertility enhancement and provides multiple use options including forage or grazing; soil conservation; and feed and food sources. Soil health was improved through increased labile soil C and microbiome diversity, activity and function (7). Selection of cowpea cultivar is critical for performance of the total system depending on use objectives of the cowpea crop and the method of maize harvest. New cowpea cultivar selection for improved growth habit, yield, and geographical adaptation (8) will aid in further improving overall crop productivity and soil health benefits of the SCCS.

Table 1. Representative biomass yields and nitrogen content of cowpea cultivars during preliminary screenings for productivity and adaptation as floor crops in the SCCS, 2014-2019.

Season – Cultivar	Biomass (kg ha^{-1})	Total N (%)	Biomass N (kg ha^{-1})
2014 'Iron and Clay'	356	3.50	11.83
2015 'Blackeye no. 5'[1,2]	338	4.84	15.48
2016 'Blackeye no. 5'	626	4.75	29.74
2019 'Blackeye no. 5'[3]	350	5.31	18.58
2019 'Blackeye no. 46'	370	5.50	20.35
2019 'Speckled Purple Hull'	300	5.60	16.80
2019 'Ozark Razorback'	290	6.01	17.70
2019 Mung bean	200	4.66	9.32
2016 'Blackeye no. 5'"Monoculture"[4]	960	4.05	38.88
Maize fodder, 5-year average	1360	1.28	17.40
Weeds, 5-year average	63	2.40	1.51

[1] Late planting and above normal seasonal precipitation in 2015
[2] Random pod samples harvested: Mean pea fresh weight, 1430 kg ha^{-1}; 3.85% N, ≈ 25% protein
[3] Poor weed control competed with floor crop establishment and growth in 2019
[4] Cowpea monoculture was solid-planting in 76-cm wide rows

Table 2. Representative biological soil health indicators measured for cowpea 'California Blackeye no. 5' and maize grown in the SCCS, 2016.

	Active carbon (mg g^{-1} soil)		WEOC (mg ml^{-1})		Glucosidase activity (µg PNP g^{-1} soil)	
	Corridor	Monoculture	Corridor	Monoculture	Corridor	Monoculture
Cowpea	500	450	52	40	125	100
Maize 'MC527'	510	465	38	32	145	125
Weedy check	150	150	22	25	78	90
$LSD_{0.05}$	85	83	11	12	46	30

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Utilization of vetches in Australian farming

Rade Matic[1]

Abstract: Vetches have been adopted by Australian farmers in crop rotation where drought is the major environmental stress. Farmers perceive vetch as a reliable, versatile legume, which can be used to improve soil fertility and contribute to increase yield and protein content in subsequent crops as well as to control cereal diseases and grass weeds. Their utilisation in the rotation is one of the best methods to reduce weed herbicide resistance and to avoid chemical contamination of paddocks. Vetch is versatile in terms of its potential end use - grain, pasture, silage, hay, or green manure.

Key words: vetch, Australia, crop rotation

In Australia, vetch is a multi-purpose crop grown mostly for grain or hay production, early grazing as green pasture or for dry grazing, and green manure. The versatility of vetch allows cropping in a wide range of soil types from light sands to heavier clay soils. Vetch is valued for its benefits to the following cereal and oilseed crops in the rotation, which are usually greater than from other pulses.

Vetches have the ability to offer substantial improvements in soil fertility by increasing nitrogen levels, structure and organic matter, as well as to offer weed and disease break for cereals in a crop rotation. Vetches are a very important crop in cereal crop rotations, having in mind that cereal crop yields following vetch are usually at least 30-50% higher than those derived from continuous cereals mono cropping (1).

Once in rotations, vetches have a number of advantages, which makes them suitable as cover crops. They are adapted to a broad range of soils ranging from acidic granite and sandstone soils through to highly alkaline clays, and they are more tolerant to acid soils than most other legumes. Vetches will generally grow over a wide range of rainfall zones from 250 mm to 650 mm annually. Additionally, vetches are large seeded and capable of being planted down into soil moisture, which contrasts with the smaller seeded fodder legumes such as medics, which often require a sequence of rainfall events after planting to ensure successful establishment. Vetches have also useful tolerance to the triazine group of herbicides (e.g., atrazine). This enables them to be double-cropped after sorghum or maize provided that excessively high rates of atrazine have not been used in the preceding summer cereal. Any likelihood of crop damage to the vetch will be further minimised by only planting in situations where there is a reasonable profile of sub-soil moisture at planting (60 cm wet soil).

In the Australian National Vetch Breeding Program (ANVBP) over 10 *Vicia* species were tested to be used as multi-purpose crops. Out of many species, there are two major species of vetch grown for hay and silage production or for grazing in Australia, common vetch (*Vicia sativa* L.) whose varieties include Morava, Rasina, Volga, Timok, Blanchfleur and Langeudoc; and Woolly pod vetch (*Vicia villosa* Roth.) whose main varieties are Capello, Haymaker, RM4 and Namoi. Both species require different management practices depending on the growing purpose. Furthermore, in today's climactic and economic environment, farmers have come to see vetch as a very versatile crop that can be also a very useful cover crop in crop rotation with cereals, as

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well as providing extremely good feed. One good thing about vetches is that during the season vetch producers can choose the best end-use for the vetch crop. If a variety does not look to be promising to finish well as a grain crop, it can be cut for hay or used as a green manure crop, and this will prove more beneficial in the long term than keeping it as a grain crop if the season finishes poorly.

The ANVBP followed the requirements of farmers, defining several main objectives for their varieties: yield for dry matter, grain and green biomass for grazing, profit on farm, increase fertility in soil, reduce cyano-toxin in grain to use to feed ruminants without limit and include in monogastric diet to the optimum level of protein, rust resistance, soft seeds (to avoid being 'weed' in following crop's), and local adaptation to particular areas.

The following table present vetches use in Australian farming and the plant characteristics that are the result of the ANVBP.

Figure 1. SARDI senior vetch breeder Rade Matic assessing *V. palaestina* in 2011 at Strathalbyn (3).

Purpose	Plant characteristics
green manuring	strong roots, good cold season growth, early nodulation, big biomass
grazing	good initial/winter growth, leaf and stem to be palatable from early stage to the end of growth
hay/silage	robust plants, disease resistant, good leaf retention, and leaf vs. stem ratio, high feeding value of hay/silage and to be able to grow in mixture with cereals for hay/silage
grain	tolerant to biotic and abiotic stresses, non-shattering, uniform maturing, high harvest ability

Table 1. Soil nitrogen (kg/ha) at five Australian sites before (A) and after (B) use of vetch for grain, hay and as green manure (2).

Site	Soil texture	pH level (H_2O)	Purpose	2002/03		2003/04		Mean (kg/ha)		Mean (kg/ha)×1.4 ×3		Increased B - A (kg/ha)
				A	B	A	B	A	B	A	B	
			Grain		34		31		32.5		136.5	54.6
Blyth	Sandy loam	8.4	Hay	21	40	18	43	19.5	41.5	81.9	174.3	92.4
			Green manure		61		58		59.5		249.9	168.0
			Grain		31		29		29.0		121.8	48.3
Lameroo	Non Wetting sand	8.3	Hay	18	36	17	33	17.5	34.5	73.5	144.9	71.4
			Green manure		48		42		45		189.0	115.5
			Grain		42		39		39.7		166.7	63.8
Kingsford	Heavy Loamy clay	7.4	Hay	27	49	22	51	24.5	50.0	102.9	210.0	107.1
			Green manure		68		71		69.5		291.9	189.0

(cont.) Table 1. Soil nitrogen (kg/ha) at five Australian sites before (A) and after (B) use of vetch for grain, hay and as green manure (2).

Site	Soil texture	pH level (H_2O)	Purpose	2002/03		2003/04		Mean (kg/ha)		Mean (kg/ha)×1.4 ×3		Increased B - A (kg/ha)
				A	B	A	B	A	B	A	B	
Peake	Loamy clay	8.2	Grain	21	27	15	36	18.0	29.3	75.6	123.1	47.5
			Hay		34		48		41		172.2	96.6
			Green manure		42		56		49		205.8	130.2
Charlick	Loamy clay	7.8	Grain	20	29	17	38	18.5	33	77.7	138.6	60.9
			Hay		40		46		43		180.6	102.9
			Green manure		62		56		59		247.8	170.1

A = soil is taken before seeding vetch.
B = soil is taken a year after seeding vetch, just before seeding following crop.
Nitrogen was calculated using formula from SARDI, Soil and Plant analysis to get total of nitrogen for 60cm/ha: [(Nitrate Nitrogen + Ammonium Nitrogen) × 1.4] × 3. For example: Blyth for 2 yrs. before vetch crop has 19.5kg/ha (nitrate + ammonium nitrogen).

1. **(19.5 × 1.4) × 3=81.9kg/ha total nitrogen (this not all available nitrogen for plant).**
2. **On the same paddocks after vetch (example for grain production) average was 32.5kg/ha. (32.5 × 1.4) × 3=136.5kg/ha**
3. **Difference in total nitrogen before and after vetch crop is: 136.5 - 81.9 = 54.6 kg/ha**

Australian farmers included and adopted vetch as a reliable, versatile legume in crop rotation where drought is the major environmental stress. They also recognized the following commercial impacts of vetches: increased total farm productivity through the reliability, versatility and productivity of vetch, improved crop yields and protein content of subsequent cereal crops on areas with a poor legume history, and increased fertility, organic matter content and greater soil stability and structure in areas of sub-optimal land management. By covering the soil during wintertime, vetches contribute to the soil fertility and increase soil nitrogen levels. The contribution of vetches to soil fertility was recorded for two years by sampling/analysing soils from Australian trial sites (Table 1). Soil samples were taken just before seeding a vetch crop, and later, before seeding of the following crops. The results shown that vetches are a valuable pre-crop and have considerable benefit to soil quality by increased soil nitrogen. Definitely, the use of vetches as cover crops and green manure is the best solution for increased nitrogen levels for early spring planted crops.

Conclusions

Vetches are crops with multipurpose end uses, as grain, pasture, hay/silage, and green manure. The ANVBP bred varieties for Australian medium/low rainfall areas, which are adapted to most areas of Australian farming land. Vetches in crop rotations can be used to improve soil fertility and contribute to increased yield and protein content in following crops and to manage cereal diseases and grass weeds. The soil nitrogen level is significantly improved with vetches as green manure and their use reduces fertilizers requirement in crop production.

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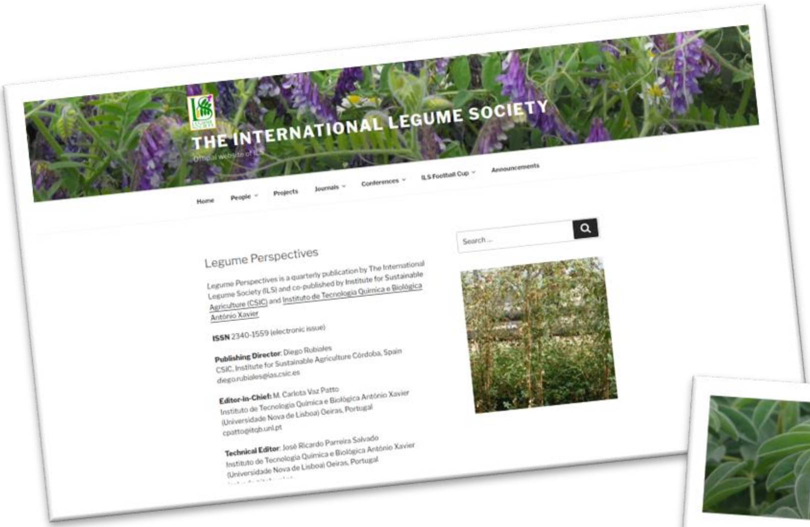

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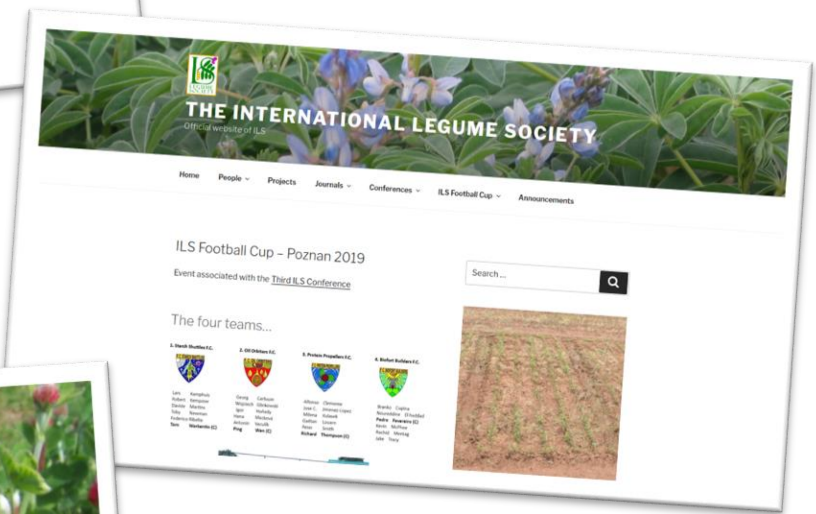

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The scope of *Legume Perspectives* comprises a vast number of disciplines, including biodiversity, plant evolution, crop history, genetics, genomics, breeding, human nutrition, animal feeding, non-food uses, health, agroecology, beneficial legume-microorganism interactions, agronomy, abiotic and biotic stresses, agroeconomy, sociology, scientometrics and networking.

The issues of *Legume Perspectives* are usually thematic and devoted to specific legume species or crop, research topic or some other issue. They are defined by the Editorial Board, led by the Editor-in-Chief with the help from Assistant Editors, who select and invite one or more Managing Editors for each issue. Having accepted the invitation, the Managing Editor agrees with the Editorial Board the details, such as the deadline for collecting the articles and a list of the tentative contributors, from whom he, according to his own and free choice, solicit the articles fitting into the defined theme of an issue. A possibility that every member of the global legume research community, with a preference of the International Legume Society members or established authorities in their field of interest, may apply to the Editorial Board to be a Managing Editor and suggest a theme for his issue is permanently open and can be done simply by contacting the Editor-in-Chief by e-mail, with a clearly presented idea, structure and authors of the potential issue.

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