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Intercropping spring wheat with grain legume for increased production in an organic crop rotation

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Abstract

The aim of the three-year study was to determine the impact of intercropping spring wheat with grain legumes on yield performance and stability, nitrogen use, weed control and grain quality. The experiment was carried out during 2007–2009 on a loamy *Endocalcari-Epihypogleyic Cambisol* (*CMg-p-w-can*) in Dotnuva (55º 24′N). Grain legumes: field pea (*Pisum sativum* L.), lupin (*Lupinus angustifolius* L.), bean (*Vicia faba* L.), vetch (*Vicia sativa* L.) and spring wheat (*Triticum aestivum* L.) were sown as intercrops and sole crops and were grown organically for grain. The productivity of spring wheat sole crop or intercrops depended on the species of grain legume, however, the results varied over the experimental years. In 2007, the vetch and wheat intercrop produced a significantly higher grain yield than wheat in sole crop or in the other intercrops. In 2008, no advantages of legume and wheat intercrops were revealed. In 2009, the yield of sole legume crops was lower compared with the total wheat and legume intercrops. The concentration of crude protein was higher in grain yield, when spring wheat had been grown in intercrops. Vetch exhibited the best suppressing ability on weeds compared to all other grain legumes investigated. The total weed mass in spring wheat intercrops with grain legume was lower compared to that in the sole crops.

Key words: grain legume, wheat, yield, protein.

Introduction

Intercropping of cereals and grain legumes is a neglected theme in agricultural science and practice in both conventional and organic farming systems (Dahlmann, Fragstein, 2006). The purpose of intercropping is to generate beneficial biological interactions between the crops. Intercropping can increase grain yields and stability, more efficiently use available resources, reduce weed pressure and sustain plant health (Hauggaard-Nielsen et al., 2003; Jensen et al., 2006). Mixing species in cropping systems may lead to a range of benefits that are expressed on various space and time scales, from a short-term increase in crop yield and quality, to longer-term agroecosystem sustainability, up to societal and ecological benefits (Malezieux et al., 2009). Design of crops to exploit diversity should ideally factor-in all traits and aspects of the production system and reach the best compromise to achieve enhanced crop function (Newton et al., 2009). Among grain legumes, peas are most common legume in crop rotations and quite productive in temperate conditions and in Lithuania also (Auškalnis, 2001). Peas are productive as main crop, but their vines also could be useful as nitrogen source (Tripolskaja et al., 2008). However, in organic framing, sole pea crops are poorly competitive against weeds compared with cereal crops. One way to control weeds in cereals is to improve the ability of the crop itself to suppress weeds (Lemerle et al., 2001; Mohler, 2001). Another way to improve the cereal competition with weeds is emphasis on the benefit of the increasing sowing density or intercropping (Liebman, Staver, 2001; Auškalnienė, Auškalnis, 2008). Several studies have shown that barley is a strong competitor towards pea when intercropped (Hauggaard-Nielsen et al., 2001; Andersen et al., 2004). Vetch and oat intercrops were widespread in Lithuania and other Baltic states over the last century in farming and research (Dovydaitis, 1992), whereas less information is available for wheat as intercrop component even with such legumes as pea or lupin. As wheat is a common crop in Lithuania, study of the intercropping dynamics would provide an insight into optimizing yield and quality of organically grown wheat.

The experiment was aimed to ascertain the influence of grain legume and spring wheat intercrops on the yield stability and quality of spring wheat in various crop combinations.

Materials and methods

The field experiment was carried out in 2007, 2008 and 2009 at the Lithuanian Institute of Agriculture in Dotnuva (55°24′ N) on a loamy *Endocalcari-Epihypogleyic Cambisol* (*CMg-p-w-can*). The soil pH varied between 7.5, humus content was 2.3%, available P – 74–79 mg kg^{-1} and K – 135–140 mg kg^{-1}. Field pea (*Pisum sativum* L.), lupin (*Lupinus angustifolius* L.), bean (*Vicia faba* L.), vetch (*Vicia sativa* L.) and spring wheat (*Triticum aestivum* L.) were sown as sole crops. Field pea cv. 'Pinochio' was sown at 1.0, lupin cv. 'VB Derliai' – at 1.5, bean cv. 'Scirocco' – at 0.6, vetch cv. 'Topaze' – at 2.5 and spring wheat cv. 'SW Estrad' – at 5.5 million seed ha^{-1}. All grain legumes were grown in dual intercrops with spring wheat and grown for grain. The intercrop design was based on the proportional replacement principle, with mixed legume grain and wheat grain at the same depth in the same rows at relative frequencies of 50:50%. The experimental plots were laid out in a complete one – factor randomised block design in three replicates. Crops were cultivated according to organic management practices.

The crops were harvested at maturity stage, in August. After threshing, the grain dry matter yield was determined. The assessment of plant crude protein concentration in the dry mater (DM) was conducted by the Kjeldahl method, multiplying it by 6.25 for legume grain or 5.7 for spring wheat grain. The air-dry mass and botanical composition of weeds was determined in an area of 0.25 m^2 in 4 places per plot at grain filling stage. The experimental data were processed by *Anova* with adapting package *Selekcija* (Tarakanovas, Raudonius, 2003). Based on the statistical evaluation of multi-data, three-year average was not calculated, because it is statistically invalid (Petersen, 1994).

The mean of temperature was less than that shown by the perennial mean of air temperature during all experimental years. The mild temperature and wet conditions were conductive to the growth of crops during the experimental year 2007 (Table 1). The spring in 2008 and 2009 was droughty; it is known that seedlings need the optimal water regime for growth at that time. In 2008, the weather conditions were droughty during the whole growing season. In June of 2009, precipitation amount was about three times as high as perennial precipitation mean of 1924–2009. Unfortunately, the amount of precipitation after the droughty spring (April and May) could have led to the crop yield fluctuation.

Table 1. Temperature and precipitation during the growing season
Data from the Dotnuva Weather Station

Month	Mean of air temperature °C			1924–2009	Precipitation mm per month			1924–2009
	2007	2008	2009		2007	2008	2009	
April	6.9	8.8	8.8	5.8	15.8	38.7	13.1	36.9
May	13.5	12.2	12.7	12.2	98.2	13.2	26.7	51.8
June	17.6	16.1	14.6	15.6	61.5	49.2	168.6	62.4
July	17.2	18.2	18.1	17.6	118.1	47.6	90.0	73.4
August	18.7	18.0	16.8	16.7	50.8	90.8	67.1	73.7

Results and discussion

The results were very varied from the first to third experimental years due to different weather conditions. The three years' grain yield analysis of variance revealed a reliable impact of years. It also provided a reliable interaction between the year and plant species. The total grain yields of grain legumes and spring wheat intercrops varied between experimental years.

In some cases, the different grain legume in intercrops significantly influenced the total intercrops' grain yield quantitative and qualitative parameters. Therefore it is advisable to discuss the yield indicators' results in more detail.

Table 2. Analysis of variance of grain yield for tree years combined, 2007–2009

Source of variation	d. f.	Mean squares of total grain yield kg ha^{-1}	F_{act}	$F_{0.05}$	$F_{0.01}$
Year	2	4416600.6	33.5**	3.18	5.04
Plants	8	5243832.9	39.7**	2.12	2.87
Year x plants	16	1669394.5	12.7**	1.84	2.37

Interspecific competition of grain legume and spring wheat was expected in intercrops due to reducing wheat and legume density (Table 3). The sole crops' productivity parameters were significantly higher compared with those of all intercrops.

Speaking about the trends of wheat and grain legume intercrops, we can presume that spring wheat was the dominant component in the intercrops. The productive stems' number significantly decreased in the intercrops, but grain number per spring wheat ear significantly increased. Grain legume and cereals can complement each other in the use of nitrogen sources in soil, but the nitrogen fixing legume can also capture atmospheric nitrogen. Therefore, grain legume density is important in intercrops for inorganic nitrogen utilisation by cereals and for significant nitrogen increasing in grain (Jensen, 1996). Reducing the recommended wheat sole crop density by 50% in the intercrop did not change the wheat crop productivity parameters, whereas grain number per earn was raised when wheat was intercropped with grain legume. Wheat and vetch intercrop had the higher amount of productive stems compared with the other intercrops. In 2008, the number of beans in the intercrops was found to be 15 stems m^{-2}. Almost the same number of the stems was in intercrop with lupin. Lupin was highly variable in the intercrop. During the growing season the grain legume can be affected by pests and drought in the ripening crop, a large part of the harvest can be lost due to lodging.

Table 3. The productivity of spring wheat and grain legume and mass of weeds in the crop structure

Treatment	Productive stems number m^{-2}			Grain number per wheat ear / legume stems m^{-2}			Air-dry mass of weeds g m^{-2}		
	2007	2008	2009	2007	2008	2009	2007	2008	2009
Wheat	527	411	521	30	35	37	11.7	25.6	8.7
Pea	84	124	99	20	14	17	16.6	98.2	34.0
Lupin	126	77	112	12	5	20	28.4	177.0	141.1
Bean	46	47	49	19	14	21	40.3	202.0	97.0
Vetch	155	227	231	17	25	24	5.0	28.1	19.2
Wheat + pea							6.3	39.8	14.4
Wheat	390	238	331	34	39	41	–	–	–
Pea	32	53	46	7	8	8	–	–	–
Wheat + lupin							7.6	55.1	12.6
Wheat	418	215	293	34	39	45	–	–	–
Lupin	22	18	49	4	2	11	–	–	–
Wheat + bean							8.8	30.3	12.8
Wheat	376	253	338	33	35	40	–	–	–
Bean	23	15	22	8	7	10	–	–	–
Wheat + vetch							8.8	22.3	11.0
Wheat	425	268	340	32	32	42	–	–	–
Vetch	61	79	101	12	20	29	–	–	–
$LSD_{0.5}$							17.7	41.9	61.9
Wheat	43.7	34.7	68.1	1.52	4.21	2.04	–	–	–
Legume	21.3	20.9	13.5	1.91	2.74	4.04	–	–	–

Grain legumes are known to be weak suppressors of weeds. As the cereal is the main weed suppressor in the intercrops, our experimental data suggested that spring wheat and grain legume dual intercrops significantly reduced the mass of annual weeds compared with sole grain legume crops, except for vetch (Table 3). In 2007, 2008 and 2009, air-dry mass of weeds was higher in pea, bean and lupin sole crops. The highest air-dry mass of *Chenopodium album* L. and *Lamium purpureum* L. and *Galega orientalis* Lam. was determined during the whole experimental period. The intercrops effectively reduced the air-dry mass of dominating weeds. Lupin intercrop efficiently suppressed *Chenopodium album* L. Vetch exhibited the best competitive power compared to all other grain legumes investigated. The trend was obtained from the first to third experimental years.

The results estimated during the three experimental years showed that the productivity of spring wheat sole crop was not always higher than that of intercrops (Table 4).

Table 4. The grain and crude protein yield of spring wheat and legume grown as sole and dual intercrops

Treatment	Grain yield kg ha^{-1}			Crude protein g kg^{-1} of dry matter			Crude protein kg ha^{-1} of grain yield		
	2007	2008	2009	2007	2008	2009	2007	2008	2009
Wheat	4132	2811	2496	115	101	122	473.6	282.1	304.8
Pea	3370	1107	2626	218	237	236	731.9	262.3	620.1
Lupin	2731	469	1323	236	239	302	641.8	103.6	402.0
Bean	3218	1011	1727	285	281	296	916.1	286.4	511.5
Vetch	2265	2214	1165	355	282	305	803.3	621.4	356.1
*Wheat + pea	3876	2509	2406	124	133	132	487.7	346.5	344.5
Wheat	3509	1932	2058	115	109	128	403.7	211.2	262.6
Pea	367	577	348	232	233	236	84.0	135.3	81.9
*Wheat + lupin	4037	1632	2654	120	109	134	483.1	177.7	407.5
Wheat	3933	1614	2235	116	108	125	457.8	173.4	280.0
Lupin	104	18	419	242	237	305	25.3	4.3	127.5
*Wheat + bean	3493	2668	2348	143	123	139	494.0	328.4	364.7
Wheat	2872	2308	1875	117	100	121	334.1	229.3	226.2
Bean	621	360	473	253	275	294	160.0	99.1	138.5
*Wheat + vetch	4387	2645	2982	155	154	167	667.5	427.2	565.3
Wheat	3860	1821	2002	122	107	133	468.1	194.8	266.1
Vetch	527	824	980	378	282	305	199.4	232.5	299.2
*$LSD_{0.5}$	246.7	446.5	382.3	15.5	7.00	7.57	74.8	102.3	96.0

Note. * – total yield.

The facts that intercropping of legumes and cereals has produced higher yields than sole cereal crops without nitrogen fertilization was noticed by several researchers (Jensen, 1996; Lauk, Lauk, 2005). In 2007, the yield of spring wheat intercrops with vetch was significantly higher compared with wheat grown as a sole crop. The grain yield of wheat intercropped with lupin was less just about 100 kg ha^{-1} than wheat sole crop produced. The yield was observed significantly lower, trends of decreasing or similar in sole crops compared with the wheat intercropped, as was noticed by researchers from other countries, is shown to have a much better utilization of plant growth resources than sole crops (Hauggaard-Nielsen et al., 2003). In 2008, the highest grain yield was estimated in spring wheat sole crop. The wheat intercrops' yields were obtained lower, however, the difference between them was insignificant. Productivity of lupin sole crop and intercropped with wheat was estimated lower than that of other crops. Mixed crops were more productive or similar to sole cereal crops. Some researchers noted that the yield of the intercrops was more stable than that of sole crops (Corre-Hellou et al., 2006). In 2009, the significantly highest grain yield was estimated in wheat intercrop with vetch than other crops. However, all intercrops produced a similar yield compared with wheat sole crop.

The concentration of crude protein is one of the most important criteria for grain quality evaluation. Analysis of grain quality showed that crude protein concentration of the intercropped spring wheat was increased compared to wheat sole crop, but was estimated significantly lower than in sole grain legume (Table 4). The crude protein concentration of wheat sole crop in grain yield ranged between 10–12%. The significantly higher crude protein concentration was observed in the total intercrops grain yields compared with the sole wheat yield. The highest crude protein concentration and yield were determined in wheat and vetch intercrop grain yield. The trend of crude protein concentration in lupin sole crop grain was similar to that in vetch and these grain legumes did not change the grain quality when intercropped with wheat. A significantly higher crude protein concentration accumulated in the yield of bean sole crop; however, bean did not have any marked effect on the crude protein concentration in the yield of intercrops compared with the other legumes. It was dependent on the amount of grain legume in intercrops. In the publication on intercropping reviewed by Hauggaard-Nielsen et al. (2006) it is reported that a relative proportion of pea in dual intercrops around 40–50% is needed in order to achieve a level of intraspecific competition inducing improvement in wheat quality parameters. Wheat and vetch cultivation in intercrop was most effective and plants were in minimal competition with each other. The vetch intercrop was defined as having significantly higher concentration of crude protein in grain compared with other intercrops. The differences between the concentrations of crude protein in yields of vetch sole crop and intercrop were found to be insignificant.

It is well known that the bread-making quality of wheat is much related to the protein content in grain, but in organic farming production, high grain quality is more difficult to achieve. The wheat grain yield was low (2002 kg ha^{-1}) when wheat was intercropped with vetch, but compared with the other cases (years or treatments), the grain yield met (13.3 g ha^{-1}) food/baking quality protein requirement of 11.5% (LST 1524:2003).

The correlation, established between crude protein concentration of total intercrop yield and crude protein concentration of grain legume suggests that the protein concentration depends on crude protein concentration of grain legume in intercrops' yield; however the correlation was not very strong (Figure 1).

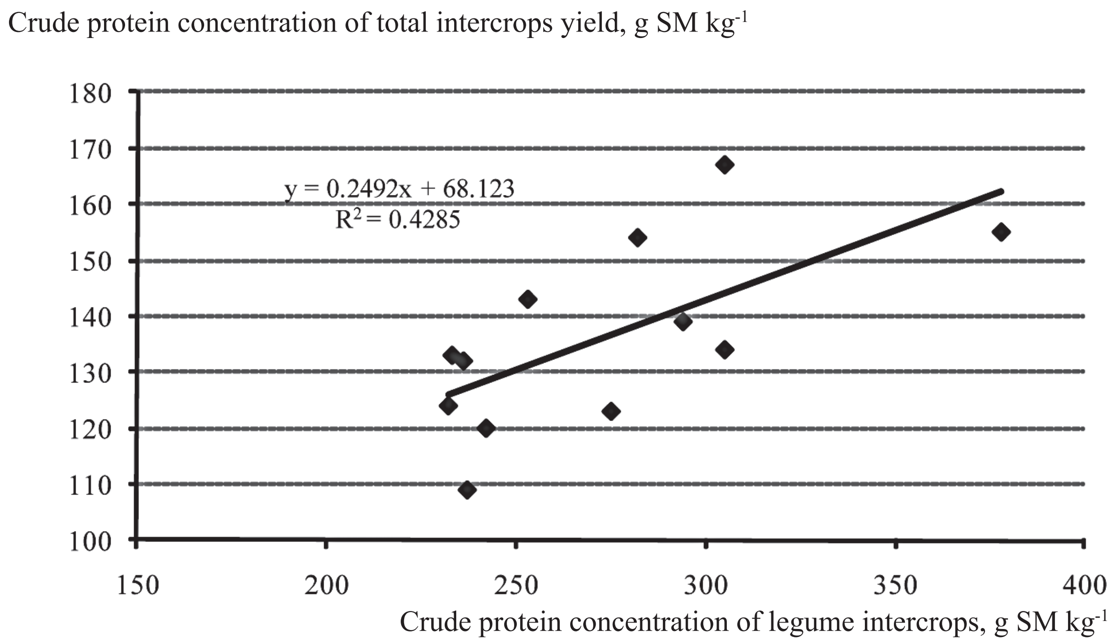

Figure 1. The dependence of crude protein concentration in total intercrop yield (y) on crude protein concentration of grain legume (x), 2007–2009

The crude protein concentration was accumulated higher in total intercrop yield when the crude protein concentration was found higher in intercropped grain legumes. Also, the crude protein total yield of intercrops was related to crude protein concentration in intercrops yield (Figure 2). It shows the relation between those values during experimental years.

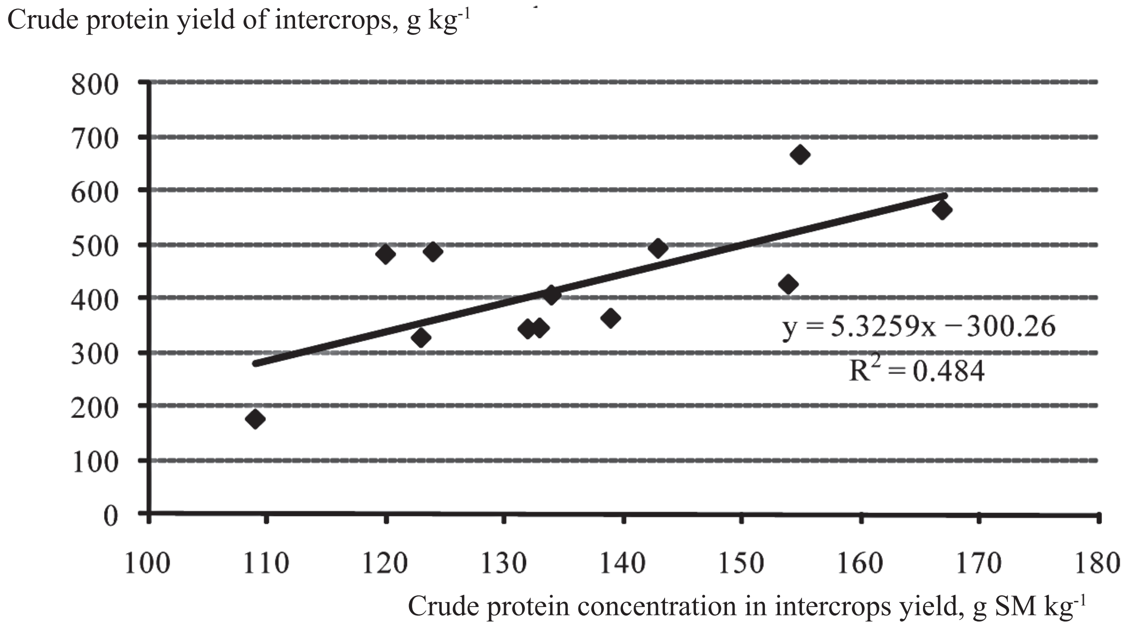

Figure 2. The dependence of crude protein total intercrop yield (y) on crude protein concentration in total intercrops' yield (x), 2007–2009

Taking into account the fact that crude protein concentration in legume grains was insignificantly different regardless of their cultivation method or the trend of crude protein concentration was increased in the wheat intercropped with grain legume, we can presume that legume and wheat intercrops could be grown in intercrops without strong competition and assimilate nutrients from environment resources.

Conclusions

1. The grain yield was significantly lower or trends of decreasing were observed for grain legume sole crops compared with the total wheat and legume intercrops' yield. Spring wheat grown in intercrops with vetch produced significantly more grain than in sole crop or other dual intercrops.

2. A significantly higher or increasing trends of crude protein concentration were estimated in total intercrops' yield. Intercropped spring wheat had better grain quality parameters. Wheat and vetch intercrop accumulated significantly more crude protein in grain compared with the other intercrops.

3. Vetch exhibited the best suppressing ability on weeds compared to all other grain legumes investigated. Weed incidence in vetch sole crop was significantly lower than that in the other legume sole crops. The total weed mass in spring wheat with grain legume dual intercrop was lower compared to that in the sole crop.

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Vasarinių kviečių ir pupinių javų auginimas mišiniuose produktyvumui didinti ekologinėje sėjomainoje

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Santrauka

Tyrimų tikslas – nustatyti pupinių javų ir vasarinių kviečių mišinių įtaką vasarinių kviečių grūdų derliaus stabilumui, azoto panaudojimui, piktžolių kontrolei bei grūdų kokybei įvairiuose vasarinių javų mišiniuose. Bandymai vykdyti 2007–2009 m. Dotnuvoje (55° 24′N), giliau karbonatingame sekliai glėjiškame rudžemyje (RDg8-k2), *Endocalcari-Ephypogleyic Cambisol* (*CMg-p-w-can*). Pupiniai javai – sėjamasis žirnis (*Pisum sativum* L.), siauralapis lubinas (*Lupinus angustifolius* L.), pašarinė pupa (*Vicia faba* L.) ir sėjamasis vikis (*Vicia sativa* L.) – buvo pasėti taikant ekologinės žemdirbystės sistemą mišinyje su vasariniu kviečiu (*Triticum aestivum* L.) ir atskirai kaip vienarūšiai pasėliai. Vasarinių pupinių javų vienarūšių pasėlių arba jų mišinių su vasariniais kviečiais produktyvumas priklausė nuo pupinio augalo rūšies. Tyrimų rezultatai varijavo skirtingų meteorologinių sąlygų metais. 2007 m. vasariniai kviečiai, augę kartu su vikiais, subrandino iš esmės daugiau grūdų nei kviečiai, augę vieni pasėlyje arba su kitais pupiniais augalais. Sausesniais 2008 m. pupinių javų bei vasarinių kviečių mišinių derlius buvo menkesnis ir mišinių pranašumas neišryškėjo. 2009 m. vienarūšių pupinių javų derlius buvo mažesnis, palyginti su bendru pupinių javų ir vasarinių kviečių mišinių derliumi. Žalių baltymų koncentracija vasarinių javų grūduose buvo didesnė, kai kviečiai auginti mišinyje su pupiniais augalais. Vikiai pasižymėjo geriausia piktžolių stelbiamąja geba, palyginti su kitais tirtais vasariniais pupiniais javais. Bendra piktžolių sausa masė buvo mažesnė vasarinių kviečių ir pupinių javų mišinio nei vienarūšių pasėlių.

Reikšminiai žodžiai: pupiniai javai, kviečiai, derlius, baltymai.