Agronomy Research **7**(1), 21-32, 2009

Dual intercropping of common vetch and wheat or oats, effects on yields and interspecific competition

R. Lauk[1] and E. Lauk[2]

[1]Institute of Agricultural and Environmental Sciences, Estonian University of Life Sciences, Kreutzwaldi St. 1, EE51014 Tartu, Estonia; e-mail: ruth.lauk@emu.ee.
[2]Institute of Agricultural and Environmental Sciences, Estonian University of Life Sciences, Kreutzwaldi St. 1, EE51014 Tartu, Estonia; e-mail: ervi.lauk@emu.ee.

Abstract. A three-year field experiment was conducted in Estonia to determine a) which combinations of vetch (*Vicia sativa* L.) intercropped with either wheat (*Triticum aestivum* L.) or oats (*Avena sativa* L.) were most suitable for mixed cultivation and b) the effect of vetch on the yield potential of cereals in different weather conditions as compared to the respective sole crops of cereals. The vetch-wheat intercrops did not produce any greater yield than wheat sole crops but the yield of vetch-oats intercrops was higher as compared to oat sole crops and vetch-wheat intercrops. The grain yield of vetch when intercropped was strongly correlated with seed density. In the years of normal precipitation and at higher vetch seed densities (over 60 seeds m^{-2}) the grain yield of intercrops was lower than that of the respective cereal sole crops. The yield of the cereal component was higher in sole crops and when increasing vetch seed density cereal grain yield decreased. The inter-specific competitiveness of wheat towards vetch increased when doubling the wheat seed density. Likewise the relatively dry growth period favored the growth of wheat as compared to vetch. Vetch-cereal intercrops produced considerably higher protein yields on the soil without any N-fertiliser than cereal sole crops and are regarded as highly suitable for organic farming.

Key words: cereals, intercrops, seed density, seed weight, *Vicia sativa*.

INTRODUCTION

Organic crop production is relatively low in inputs and general cost investments compared to those management strategies dependent on chemical fertilisers and pesticides. Organic farming is regarded as an agricultural practise not harmful to either man or the environment, but from a farmer's point of view it includes risks, e.g. in the case of both abiotic and biotic factors. In the present study the main focus will be on crop nutrition using only limited amounts of animal manure.

Among the recommendations to overcome the difficulties to supply nutrients according to crop demand is that of expanding the cropping area of atmospheric nitrogen (N) fixing, including that of legume-cereal intercrops (Elgersma et al., 2000; Mueller & Thorup-Kristensen, 2001; Jensen et al., 2004). Legume-cereal mixed intercrops could be used on arable land. Intercropping can be seen as the practical application of diversity, competition and facilitation in arable cropping systems. Hauggaard-Nielsen et al. (2003, 2006) found that legume-cereal mixed intercrops are better at exploiting natural resources as compared to the respective sole crops of different plant species. Legumes can cover their N demand from atmospheric N_2

(Trenbath, 1976; Hauggaard-Nielsen et al., 2001a) and therefore legumes intercropped with cereals compete less for soil mineral N. The above-ground plant material of common vetch may contain more than 100 kg N ha^{-1} originating from N_2-fixation (Papastylianou, 1999; Mueller & Thorup-Kristensen, 2001). However, in certain years with unfavourable growing conditions, the amount of vetch N_2-fixation may be considerably lower. Leguminous atmospheric N_2 accumulation depends, to a great extent, on specific soil-plant interactions throughout the peculiarities of the growth period influenced by both the farming system as such and in particular fertilisation strategies (Sidiras et al., 1999; Peoples et al., 2001).

Legume-cereal intercrops may produce higher grain and protein yields as compared to the respective cereal sole crops (Jensen, 1996; Hauggaard-Nielsen et al., 2001a; Lauk & Lauk, 2005) and show greater yield stability across years than when growing legumes and cereals as sole crops (Willey, 1979; Ofori & Stern, 1987). Legume-cereal intercrops reduce their advantage over sole crops in the case where N fertilisers are applied, reducing the inter-specific complementarity, often reported as reducing the proportion of legumes in the total harvested intercrop yield (Jensen, 1996, Ghaley et al., 2005). In general it can be concluded that under growing conditions where cereal sole crops produce rather high yields, intercropping with legumes has no advantages over cereal sole crops (Ofori & Stern, 1987). However, when evaluated over a number of years the intercrops are expected to show more stable yields than the specific sole crops.

Legume sole crops can be grown under organic farming conditions but they have some disadvantages compared to legume-cereal intercrops. Sole crops of common vetch and other leafy long-straw pea varieties may often lodge heavily, making combine harvesting difficult; great yield losses can occur. When intercropping vetch with cereals like wheat or oats as a standing support culture, lodging can be avoided. Furthermore, the often considerable weed infestation level in legume sole crops is reported to be significantly reduced when legumes are intercropped with cereals (Mohler & Liebman, 1987; Liebman & Dyck, 1993; Rauber et al., 2001; Talgre et al., 2005; Hauggaard-Nielsen et al., 2006).

Under Estonian growing conditions common vetch is regarded as the most suitable legume for organic farming. The hypothesis of the present study was that intercropping common vetch with cereals (wheat and oats) produces higher protein yields without supplying N fertiliser as compared to the respective sole crops. The aim of the study was to increase the knowledge of complementarity between relatively distant plant species and their joint yield output, thereby revealing the degree of interspecific competition. Of special interest is understanding how the yield potential of the different species is affected by competition between vetch and cereals.

MATERIAL AND METHODS

The field experiment was conducted over a three-year period from 2000-2002 at the Plant Biology experimental station of the Department of Field Crops and Grasslands (58°23´N, 26°44´E) of the Estonian University of Life Sciences (EMU). Estonia is located beside the Baltic Sea and sufficiently close to the north-eastern waters of the Atlantic Ocean for significant influence; consequently Estonia's climate is highly changeable. The springs are chilly, the summers are often relatively short and cool and autumn, generally long and mild.

The experiment was established on a pseudopodzolic, moderately moist soil having a slightly sandy-clayey texture. The soil properties were as follows: PH_{KCl} of the ploughed layer was 4.9–6.1, organic matter content 2.3–3.2%, and the available phosphorus and potassium contents (determined using the Egner-Riehm-Domingo method) 76–174 mg kg^{-1} and 109–204 mg kg^{-1}. The pre-crop of the experiment was spring wheat (sequence of crops: wheat-barley-red clover-potato-wheat), and mineral fertilisers were not used at sowing.

The field experiment was carried out as a three-series test:

Series 1 (wheat250+vetch): the sowing rate of the spring wheat (*Triticum aestivum* L. cv. Tjalve) was identical in all variants of the series: 250 germinating seeds per m^{-2}, common vetch (*Vicia sativa* L. cv. Carolina) sown at different seed densities;

Series 2 (wheat500+vetch): the sowing rate of the spring wheat (*Triticum aestivum* L. cv. Tjalve) was identical in all variants of the series: 500 germinating seeds per m^{-2}, common vetch sown at different seed densities;

Series 3 (oats250+vetch): the sowing rate of the oats (*Avena sativa* L. cv. Jaak) was identical in all variants of the series: 250 germinating seeds per m^{-2}, common vetch sown at different seed densities.

The sown germinating seed density of common vetch varied in all the test series between 0 to 120 m^{-2}. Thus, each test series included 11 different variants: 0, 12, 24, 36, 48, 60, 72, 84, 96, 108 and 120 vetch seeds m^{-2}. The variants of the test series had one replication as regression analysis was planned as the statistical processing method of the experimental data on the basis of the demonstrations by Little & Hills (1972) and Mead et al. (1993), that regression analysis enables the calculation of the error of the tests series with only one replication. We have described the experimental methodology and recommended regression analysis for research on experiments involving the use of fertilisers (Lauk, 1995), vetch-wheat mixes (Lauk et al., 1996; Lauk et al., 2004) and herbicides (Lauk & Lauk, 2000). All the test series had a control variant (sole stands of cereals) in two replications, i.e. on two experimental plots. Two control variants per test series enable better fixation of the starting point of the regression (Lauk & Lauk, 2000).

Vetch and cereal seeds were mixed prior to sowing and were sown in the same row using a special plot drill. The area of the test plots was 10 square meters.

Plant growing conditions in 2000 and 2001 were favourable, and the amount of precipitation was 285 and 330 mm, respectively, during the growth period. The cereals were, in 2000 and 2001, lower in height when intercropped with vetch. The year 2002 was unfavourable for the growth of plants (Figs 1, 2). The air temperature was considerably higher than usual during the growth period and precipitation was only 147 mm, or nearly half the norm. Common vetch suffered most from the drought, and was lower in height when grown together with cereals.

Following harvesting, grain yields were determined separately by components and as total yield in intercrops variants. The yields were calculated at 14% humidity content. Also, 1000-seed weight of the seeds and the protein content of the yields in all variants were determined. Protein yields per surface unit were calculated on the basis of the protein content of the yield and dry matter yields. The average results of 2000 and 2001 were subjected to a separate regression analysis from the results of 2002 and

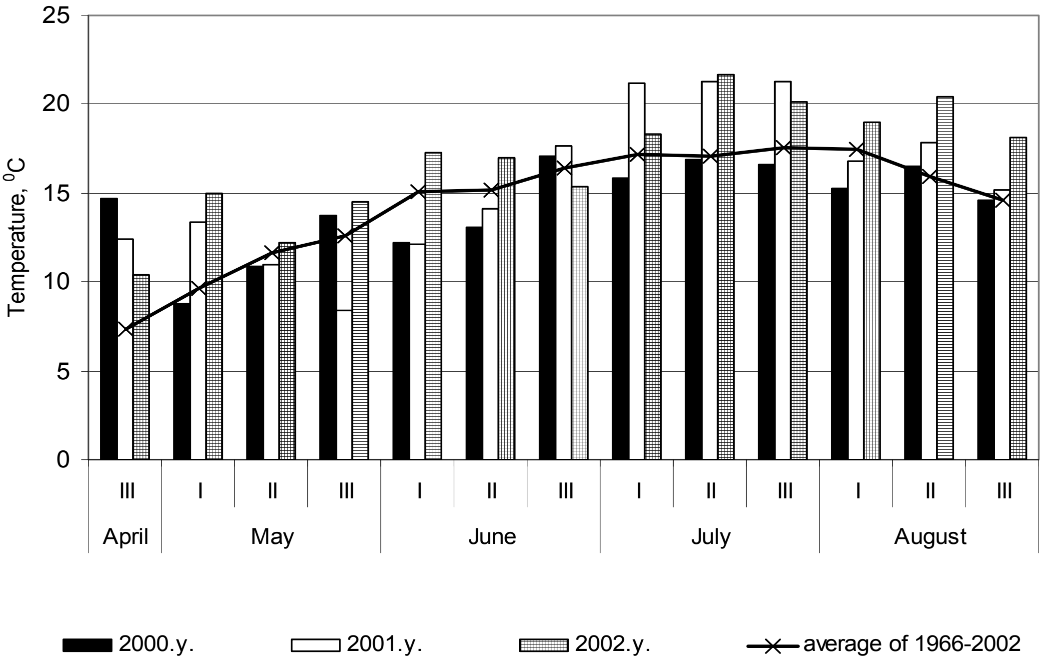

Fig. 1. The air temperature (°C) of experimental area during growing season from 2000 to 2002.

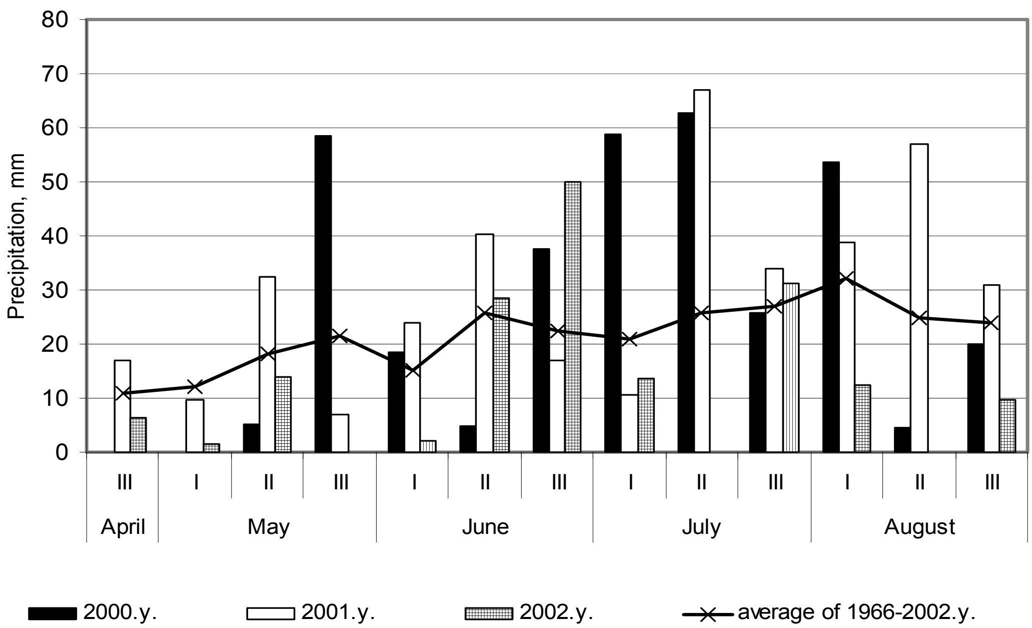

Fig. 2. The precipitation (mm) of experimental area during growing season from 2000 to 2002.

will be discussed separately in the article due to widely differing meteorological conditions. The regression analysis used a quadratic equation ($y = a + bx + cx^2$), with the independent variable being the seed density of vetch, varying between 0–120, and the respective dependent variables being, respectively, yields and protein yields (kg ha^{-1}) and 1000-seed weight of grain (g).

In all the test series, standard errors (*S.E.*) for dependent variables and confidence limits ($CL_{0.05}$ – level of statistical significance, $p = 0.05$) were calculated according to the methodology elaborated (Lauk & Lauk, 2000). The confidence levels of the correlations in the test series were assessed by means of the control values of the correlation coefficients (R), taken from the relevant tables on the basis of degrees of freedom (Little & Hills, 1972). All the numerical values given in the tables were calculated on the basis of the regression equations obtained from regression analysis. To avoid excessive numbers, results have been calculated for the sowing rates 0, 20, 40, 60, 80, 100 and 120 vetch seeds m^{-2}.

RESULTS

As averaged for two years (2000 and 2001), vetch-wheat intercrops produced no higher yields than sole wheat crops (Table 1). However, the yield of intercrops exceeded that of sole oats stands in vetch-oats intercrops (series 3). On the whole, intercropping of vetch and oats produced higher yields than vetch-wheat intercrops. Maximum yield (3947 kg ha^{-1}) was gained on a soil with no N-fertiliser in vetch-oats intercrops at vetch seed density of 40 m^{-2}. Starting from the vetch seed density of 40 m^{-2}, increasing the density caused a more intense yield decrease of intercrops in all test series ($R = 0.920$–0.978; $p<0.001$) and, therefore, the yield of intercrops became the lowest at the maximum vetch seed density. The negative effect of increasing vetch seed density on the grain yield of intercrops was the greatest in test series 1, where wheat was sown in the mix at a lower seed density.

Grain yield was greatest (3323–3624 kg ha^{-1}) in sole crops of cereals, with sole oats crops producing a greater yield compared to sole wheat crops ($p<0.05$). The doubling of wheat seed density had no significant effect on the yield of sole wheat crops ($p>0.05$). Vetch and increasing its seed density had a strong negative effect on grain yields of cereals in all cases ($R = 0.970$–0.995; $p<0.001$). Due to the negative effect of increasing the seed density of vetch, the wheat yield in test series 1 decreased more than three times compared with the yield of sole wheat stands, in test series 2, more than twice, and oats yield in test series 3, nearly 1.6 times, and the proportion of grain yield of cereals in the intercrop yield decreased to 45, 58 and 68 per cent, respectively. The seed yield of vetch intercropped with cereals was the highest at the vetch seed density of 80 m^{-2} and, depending on the test series, vetch seed yield was between 1150–1335 kg ha^{-1}.

The yields of vetch-cereal intercrops, in a dry year (2002), were considerably lower than the average of the two previous years. In the first two tests series, where vetch was intercropped with wheat, changes in the intercrops yield were very small, and there were no significant relations between the vetch seed density and the intercrops yield ($R = 0.213$–0.351; $p>0.05$). In test series 3 (vetch + oats), the yield change of intercrops was significant ($R = 0{,}936$; $p<0.001$) and, starting from the vetch seed density of 20 m^{-2}, increasing vetch seed density caused a decrease of yield in vetch-oats intercrops. Because of the meteorological conditions in 2002, grain yields in sole crops were lower by 40–45 % than the average of 2000 and 2001. The decrease in the yield of grain when intercropped with vetch was a consequence of increasing vetch seed density, in 2002 (R = 0.838–0.946; p<0.01) but was less intense than during the two previous years. The main element of the intercrop yield was cereal, and indeed in 2002 there were no cases in which the yield was less than 81%. When intercropped with wheat, vetch seed yields were 350 kg ha^{-1} maximum in 2002, whereas, when intercropped with oats, vetch seed yields were under 200 kg ha^{-1}.

Table 3 presents the 1000-seed weight of cereals as the average of 2000 and 2001. Cereals grown together with vetch developed considerably smaller grains. A strong negative correlation occurred between increases in vetch seed density and 1000-seed weight of cereals (R = 0.925–0.988; p<0.001). The 1000-seed weight of wheat decreased the most, by 6.1–6.3 g. The 1000-seed weight of oats decreased by up to 3.6 g. The formation of smaller grains was one of the reasons for the decrease of the yield of cereal intercropped with vetch.

The changes in vetch seed density considerably affected the protein yields of vetch-cereal intercrops as the average of 2000 and 2001. Intercropping of cereals and vetch produced considerably higher protein yields than sole cereal crops. The maximum protein yields (546–593 kg ha^{-1}) in intercrops were gained at vetch seed densities of 60–80 m^{-2} in the sown seed mix (Table 3).

Data of the research revealed that, in the dry growing season of 2002, common vetch and the changes in vetch seed density had no significant effect (R = 0.426; p>0.05) on the 1000-seed weight of wheat in test series 2 (Table 4). Vetch, however, had a significant effect on the 1000-seed weight of oats (R = 0.696; p<0.05) but the negative effect was substantially smaller in 2002 than the average of 2000 and 2001.

The protein yields were adversely affected by the lack of precipitation in 2002 compared with sole cereal crops. Correlations between vetch seed density and protein yields of intercrops were relatively weak and not significant (R = 0.391–0.595; p>0.05).

DISCUSSION

Legume-cereal intercropping has produced highly different results and conclusions, whereas occurrence or non-occurrence of advantages of legume-cereal intercrops depended considerably on the environmental conditions and conditions created by farmers. Intercropping of legumes and cereals has produced higher yields than sole cereal crops primarily on soils with no N-fertiliser (Jensen, 1996; Hauggaard-Nielsen et al., 2001a; Lauk & Lauk, 2005). At the same time, research has shown (Jensen, 1996; Hauggaard-Nielsen et al., 2001a) that when cereal in sole crops is provided with favourable nitrogen feeding conditions through the use of mineral N-fertilisers, intercrops have no advantages over sole cereal crops. Ofori & Stern (1987) indicate that legume-cereal intercrops lose their advantage over sole cereal crops in conditions that favour the growth development and consequent yields of cereal in sole crops. Lauk & Lauk (2006) ascertained that vetch-wheat intercrops lose their grain yield advantage over sole wheat crops in conditions when the yield of sole wheat crops exceeds 3000 kg ha^{-1}. Whereas the sum of precipitation during the growth period of intercrops should be about 300 mm, with substantially lower accumulated totals of precipitation, yields of vetch-wheat intercrops are lower and also lose their advantage over sole wheat crops. The factual material presented in the article is a confirmation of that. The yield of sole wheat crops on soil without any supply of N-fertiliser was, as the average of 2000 and 2001, over 3000 kg ha^{-1} and the grain yield of vetch-wheat intercrops was not higher than the yield of sole wheat stands. The yield of vetch-wheat intercrops depended considerably on the vetch seed density and, at seed densities higher than the optimum of over 60 m^{-2}, the grain yield of intercrops was substantially lower than the yield of sole wheat crops. The yield of sole oats crops was slightly over 3600 kg ha^{-1} , however the yield of vetch-oats intercrops was higher to some extent than that of sole oats crops. The intercrops did not, in 2002, produce higher yields than sole wheat and oats crops, despite the fact that the yields of sole wheat and oats crops were approximately 2000 kg ha^{-1}. The reason was the small amount of precipitation during the growing season, making up only 50 % of the norm.

Several studies (Hauggaard-Nielsen et al., 2001b; Rauber et al., 2001; Andersen et al., 2004) have revealed that legumes in intercrops are greatly affected and oppressed by the cereal component and, as Rauber et al. (2001) indicate, this is especially evident with short-straw legume varieties. The research methods used (identical seed densities of cereals in the variants of the test series) enabled us to establish the development potential of the relatively long-straw common vetch on the yield potential of cereals. Therefore, we can state that while vetch had a very strong negative effect on the grain yield of cereals in intercrops, the negative effect was even greater at increased vetch seed densities. The reason that intercrops in certain conditions have no advantages over sole stands is the strong competition of legumes with cereals. Doubling the seed density of wheat increased the competitiveness of wheat intercropped with vetch, and the decrease in wheat yield was less intense, compared with lower wheat seed densities. One of the reasons for decreased yields of cereals intercropped with vetch was the formation of considerably smaller grains in the years of normal precipitation, when cereal was lower in height than intercrops. Hauggaard-Nielsen et al. (2006) stated that legumes exert strong pressure on cereals in the second half of the vegetation period, which is the time of grain formation. In a dry growing season, when vetch was lower in height than intercrops with cereals, cereals were remarkably more competitive than vetch, and there was no considerable decrease in the 1000-seed weight of grain. Also the decrease of cereal yield due to its intercropping with vetch and increase of seed density of vetch was considerably less intense than in normal years.

Seed yields of vetch intercropped with cereals were up to 1335 kg ha^{-1}. Doubling the wheat seed density exerted a negative effect on the seed yield of vetch, due to which the proportion of wheat in the yield of mixed stands increased and the proportion of vetch decreased. Oats revealed stronger competitiveness towards vetch than wheat and, therefore, the proportion of oats in intercrop yields was greater than that of wheat. Vetch-cereal intercrops can be grown for several purposes, as feed or to gain vetch seed yield (to propagate vetch seeds). When vetch is intercropped with cereals for seed, wheat should be preferred over oats as the support culture, by using a smaller wheat seed density to obtain a possibly high seed yield. If intercrops are grown for fodder, vetch-oats crops should be preferred as such intercrops produce higher yields compared with vetch-wheat intercrops. When growing vetch for seed it is preferable to use wheat as the cereal component in the mix. In dry years, cereals showed very strong competitiveness towards vetch. The dry soil probably caused a considerable decrease in the normal fixation of atmospheric nitrogen by vetch. Weather conditions may also cause great differences in atmospheric nitrogen amounts bound by vetch (Mueller & Thorup-Kristensen, 2001).

An advantage of legume-cereal intercrops, compared with sole cereal crops, is their larger protein yield (Hauggaard-Nielsen et al., 2001a; Lauk & Lauk, 2006). The present research mostly confirmed this advantage. Vetch-cereal intercrops on a soil without any supply of N-fertiliser produced considerably larger protein yields compared with sole cereal crops, whereas the protein yields of the intercrops depended greatly on the seed density of vetch. High vetch seed densities (over 80 m^{-2}) proved indecisive. An exception was a year with a dry growing season, when vetch-cereal intercrops produced protein yields not much greater than sole cereal crops.

CONCLUSIONS

As an average of two years (2000 and 2001), the grain yield of vetch-wheat intercrops was not higher than the yield of sole wheat stands. The yield of vetch-oats intercrops was higher than that of sole oat crops. Maximum yield (3947 kg ha^{-1}) was gained on a soil with no N-fertiliser in vetch-oats intercrops at vetch seed density of 40 m^{-2}. The yields of vetch-cereal intercrops, in the year with a dry growth period (2002), were considerably lower than the average of the two previous years. Doubling (500 germinating seeds per m^{-2}) the wheat seed density increased the inter-specific competitiveness of wheat towards vetch. When cereals were grown together with vetch they developed considerably smaller grains. A strong negative correlation occurred between increases in vetch seed density and 1000-seed weight of cereals. The formation of smaller grains was one reason for the decrease of the yield of cereal intercropped with vetch.

As the average of 2000 and 2001, intercropping of cereals and vetch produced considerably higher protein yields than sole cereal crops (389-402 kg ha-1). The maximum protein yields (546-593 kg ha-1) in intercrops were gained at vetch seed densities of 60-80 per m^{-2} in the sown seed mix. In the dry growth season correlations between vetch seed density and protein yields of intercrops were relatively weak and not significant.

If intercrops are grown for fodder, vetch-oats crops should be preferred as they produce higher yields compared with vetch-wheat intercrops. When growing vetch for seed it is preferable to use wheat as the cereal component in the mix. Vetch-cereal mixes should be recommended to farmers, as they ensure a relatively good harvest and high protein yield on soil without N-fertiliser.

Table 1. Formation of the yield of grain and vetch-cereal intercrops, depending on the seed density of vetch, average of 2000 and 2001.

Seeding rate of vetch, seeds m^{-2}	Series 1 (wheat250+vetch)			Series 2 (wheat500+vetch)			Series 3 (oats250+vetch)		
	yield (kg ha^{-1})		percentage of wheat in yield	yield (kg ha^{-1})		percentage of wheat in yield	yield (kg ha^{-1})		percentage of oats in yield
	vetch + wheat mixes	wheat		vetch + wheat mixes	wheat		vetch + oats mixes	oats	
0	-	3323	100	-	3451	100	-	3624	100
20	3343	2702	81	3371	2902	86	3923	3309	84
40	3244	2170	67	3265	2443	75	3947	3024	77
60	3059	1726	56	3129	2075	66	3872	2767	71
80	2791	1369	49	2963	1799	61	3699	2540	69
100	2428	1101	45	2767	1614	58	3426	2342	68
120	2000	921	46	2542	1520	60	3054	2253	74
S.E.	30	24		36	46		17	36	
$CL_{0.05}$	67	53		82	105		38	81	
R	0.974	0.995		0.920	0.974		0.978	0.970	

Table 2. Formation of the yield of grain and vetch-cereal intercrops, depending on the vetch seed density in 2002.

Seeding rate of vetch, seeds m^{-2}	Series 1 (wheat250+vetch)			Series 2 (wheat500+vetch)			Series 3 (oats250+vetch)		
	yield (kg ha^{-1})		percentage of wheat in yield	yield (kg ha^{-1})		percentage of wheat in yield	yield (kg ha^{-1})		percentage of oats in yield
	vetch + wheat mixes	wheat		vetch + wheat mixes	wheat		vetch + oats mixes	oats	
0	-	1830	100	-	2083	100	-	2025	100
20	1805	1671	93	2071	1922	93	1938	1852	96
40	1786	1549	87	2068	1805	87	1859	1716	92
60	1766	1465	83	2057	1733	84	1797	1618	90
80	1746	1417	81	2039	1706	84	1751	1557	89
100	1726	1407	82	2012	1723	86	1721	1534	89
120	1707	1434	84	1978	1785	90	1708	1547	90
S.E.	30	22		40	25		13	13	
$CL_{0.05}$	67	50		90	58		28	28	
R	0.351	0.899		0.213	0.838		0.936	0.972	

Table 3. 1000-seed weight of cereals, depending on vetch seed density and the formation of protein yields of vetch-cereal intercrops, average of 2000 and 2001.

Seeding rate	1000-seed weight of cereals (g)			Protein yields of vetch-cereal intercrops (kg ha^{-1})		
of vetch, seeds m^{-2}	series 1 (wheat250+vetch)	series 2 (wheat500+vetch)	series 3 (oats250+vetch)	series 1 (wheat250+vetch)	series 2 (wheat500+vetch)	series 3 (oats250+vetch)
0	34.8	34.0	35.0	402	400	389
20	31.8	32.1	34.0	506	472	477
40	29.8	30.6	33.2	570	520	534
60	28.8	29.4	32.5	593	545	532
80	28.7	28.5	32.0	575	546	560
100	29.6	27.9	31.6	516	523	528
120	31.4	27.7	31.4	416	503	466
S.E.	0.18	0.12	0.08	7.5	5.5	6.8
$CL_{0.05}$	0.42	0.27	0.20	17.0	12.5	15.3
R	0.962	0.983	0.988	0.937	0.938	0.933

Table 4. 1000-seed weight of cereals, depending on the vetch seed density and the formation of protein yields of vetch-cereal intercrops in 2002.

Seeding rate	1000-seed weight of cereals (g)			Protein yields of vetch-cereal intercrops (kg ha^{-1})		
of vetch, seeds m^{-2}	series 1 (wheat250+vetch)	series 2 (wheat500+vetch)	series 3 (oats250+vetch)	series 1 (wheat250+vetch)	series 2 (wheat500+vetch)	series 3 (oats250+vetch)
0	41.5	39.3	36.3	222	248	214
20	41.1	39.2	36.5	238	273	218
40	40.8	39.0	36.6	248	288	221
60	40.6	39.0	36.5	254	295	222
80	40.4	39.0	36.3	256	293	222
100	40.3	39.2	35.9	253	283	220
120	40.3	39.4	35.3	245	264	216
S.E.	0.10	0.16	0.10	4.6	6.4	2.0
$CL_{0.05}$	0.22	0.36	0.22	11.0	15.0	5.0
R	0.820	0.426	0.696	0.594	0.595	0.391

ACKNOWLEDGEMENTS

The present study has been made possible thanks to the financial support of Estonian Scientific Foundation (Grant No 4815).

REFERENCES

Andersen, M. K., Hauggaard-Nielsen, H., Ambus, P. & Jensen, E. S., 2004. Biomass production, symbiotic nitrogen fixation and inorganic N use dual and tri-component annual intercrops. *Plant and Soil*, 266, 273–287.

Elgersma, A., Schlepers, H. & Nassiri, M., 2000. Interaction between perennial ryegrass and white clover under contrasting nitrogen availability:productivity, seasenal patterns of species composition, N_2 fixation, N transfer and N recovery. *Plant and Soil*, 221, 281-299.

Ghaley, B.B., Hauggaard-Nielsen, H., Hogh-Jensen, H. & Jensen, E. S., 2005. Intercropping of wheat and pea as influenced by nitrogen fertilization. *Nutrient Cycling in Agrosystems*, 73, 201–212.

Hauggaard-Nielsen, H., Ambus, P. & Jensen, E. S., 2001a. Interspecific competition, N use and interference with weeds in pea-barley intercropping. *Field Crops Research*, 70, 101–109.

Hauggaard-Nielsen, H., Ambus, P. & Jensen, E. S., 2001b. Temporal and spatial distribution of roots and competition for nitrogen in pea-barley intercrops – a field study employing ^{32}P technique. *Plant and Soil*, 236, 63–74.

Hauggaard-Nielsen, H., Ambus, P. & Jensen, E. S., 2003. The comparison of nitrogen use and leaching in sole cropped versus intercropped pea and barley. *Nutrient Cycling in Agroecosystems*, 64, 289–300.

Hauggaard-Nielsen, H., Andersen, M. K. & Jørnsgaard, B. & Jensen, E. S., 2006. Density and relative frequency effects on competitive interactions and resource use in pea-barley intercrops. *Field Crops Research*, 95, 256–267.

Jensen, E. S., 1996. Grain yield, symbiotic N_2 fixation and interspecific competition for inorganic N in pea-barley intercrops. *Plant and Soil*, 182, 25–38.

Jensen, C. R., Joernsgaard, B., Andersen, M. N., Christiansen, J. L., Mogensen V. O., Friis, P. & Petersen C. T., 2004. The effect of lupins as compared with peas and oats on the yield of the subsequent winter barley crop. *European Journal of Agronomy*, 20, 405–418.

Lauk, E., 1995. Regression analysis: a good method for analysing the field experiments data. *Proceedings of the Forth Regional Conference on Mechanization of Field Experiments* (IAMFE/BALTIC '95). Kaunas/Dotnuva, Lithuania, 35–41.

Lauk, E., Jaama, E. & Leis, J., 1996. Methodological additions to research on mixed seeds of agricultural cultures. *Proceedings of the Tenth International Conference on Mechanization of Field Experiments* (IAMFE/FRANCE '96). Paris/Versailles, France, 156–160.

Lauk, E., Lauk, R. & Lauk, Y., 2004. Experimental planning and methods in regression analysis. *–Proceeding of the 12^th^ International Conference and Exhibition on Mechanization of Field Experiments* (IAMFE/RUSSIA '04). Saint–Petersburg, Pushkin, Russia, 58–63.

Lauk, E. & Lauk, R., 2005. The yields of legume – cereal mixes in years with high – precipitation vegetation periods. *Latvian Journal of Agronomy*, 8, 281-285.

Lauk, E. & Lauk, Y., 2000. Methodology of experiment and data processing in research works on herbicides. *Aspects of Applied Biology*, 61, 41–46.

Lauk, R. & Lauk, E., 2006. Yields in vetch-wheat mixed crops and sole crops of wheat. *Agronomy Research*, 4, 37–44.

Liebman, M. & Dyck, E., 1993. Crop rotation and intercropping strategies for weed management. *Ecological Applications*, 3, 92–122.
Little, T. M., & Hills, F. J., 1972. Statistical Methods in Agricultural Research. Berkeley, California.
Mead, R., Curnow, R. N. & Hasted A. M., 1993. Statistical Methods in Agriculture and Experimental Biology. Second edition. Chapman & Hall.
Mohler, C. L. & Liebman, M., 1987. Weed productivity and composition in sole crops and intercrops of barley and field pea. *Journal of Applied Ecology*, 24, 685–699.
Mueller, T. & Thorup-Kristensen, K., 2001. N-fixation on selected green manure plants in an organic crop rotation. *Biological Agriculture and Horticulture*, 18, 345–363.
Ofori, F. & Stern, W.R., 1987. Cereal-legume intercropping systems. *Advances in Agronomy*, 41, 41–90.
Papastylianou, I., 1999. Estimation of nitrogen fixed by legumes in long-term vs. short-term cropping systems. *Agronomy Journal*, 91, 329–334.
Peoples, M. B., Bowman, A. M., Gault, R. R., Herridge, D. F., McCallum, M. H., McCormick, K. M., Norton, R. M., Rochester, I. J., Scammell, G. J. & Schwenke, G. D., 2001. Factors regulating the contributions of fixed nitrogen by pasture and crop legumes to different farming systems of Eastern Australia. *Plant and Soil*, 228, 29–41.
Rauber, R., Scmidtke, K. & Kimpel-Freund, H., 2001. The performance of pea (*Pisum sativum* L.) and its role in determining yield advantages in mixed stands of pea and oat (*Avena sativa* L.). *Agronomy and Crop Sciense* 187: 137-144.
Sidiras, N., Avgoulas, C., Bilalis, D. & Tsougrianis, N., (1999). Effects of tillage and fertilization on biomass, roots, N-accumulation and nodule bacteria of vetch (Vicia sativa cv. Alexander). *Agronomy and Crop Science*, 182, 209–216.
Talgre, L., Lauringson, E., Lauk, E. & Lauk, R., 2005. Weediness of mixed crops depending on weather conditions and sowing rate of leguminous. *Latvian Journal of Agronomy*, 8, 243–247.
Trenbath, B. R., 1976. Plant interactions in mixed crop communities. R. I. Papendick, P. A. Sanchez, G. B. Triplett, editors. Multiple cropping. *American Society of Agronomy Special Publication*, 27, 129-170.
Willey, R. W., 1979. Intercropping – Its importance and research needs. Part 1. Competition and yield advantages. *Field Crop Abstract*, 32, 1–10.