Journal of Animal and Veterinary Advances 12 (4): 509-520, 2013
ISSN: 1680-5593

Competitive Effects of Plant Species under Different Sowing Ratios in Some Annual Cereal and Legume Mixtures

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Abstract: Competitive ability of common vetch (*Vicia sativa* cv Karaelci) and Hungarian vetch (*Vicia pannonica* cv Population) with barley (*Hordeum vulgare* cv Tokak) and oat (*Avena sativa* cv Gezkoy) were tested under greenhouse conditions at Ataturk University, Erzurum, between the date of 14 November, 2011 and 11 April, 2012. The vetches and cereals were sown at a ratio of 100:0, 75:25, 50:50 and 25:75. The cereals grown with common vetch had a higher Relative Height Growth Rate (RHGR). The highest RHGR was recorded when barley had a 25 or 50% sowing ratio in the mixture, although the RHGR of oat was not affected by the vetches. Whereas, the sowing ratio did not affect the RHGR of vetches common vetch grown with barley had higher RHGR. Total biomass production of cereals was higher when their sowing ratio was 25%. The cereals grown with Hungarian vetch produced more total biomass per plant than the other. Total biomass production of the vetches was the highest when grown at a sowing ratio of 50:50 and the vetches produced more total biomass when grown with barley. Leaf Mass Ratio (LMR) of cereals was higher when grown with common vetch. Vetches had least LMR at a sowing ratio of 50:50. Barley in the mixture resulted in decreases in the LMR of vetches. Since, barley grown with common vetch at a lower sowing ratio produced more above ground biomass, the Stem Mass Ratio (SMR) increased. Below ground production of cereals was negatively affected, although their above ground production was positively affected by vetches competition whereas, competitive effect of cereals on vetches was negative on above ground production while positive on below ground production in mixed cropping conditions. The results showed that a better facilitative effect between tested materials occurred at the mixture of common vetch with barley at 50:50 or lower barley sowing ratio. In conclusion, a barley-common vetch mixture should be suggested for cold climate areas in rotation systems to establish environmentally friendly cropping systems.

Key words: Mixed cropping, RHGR, LMR, SMR, RMR, competition

INTRODUCTION

Vetches and cereals mixtures are commonly used for hay production in temperate climates. When the components of mixture are complementary to each other, higher yield occurs as a result of effective use of environmental resources such as light, water and nutrient. The suitable mixture of legumes with grasses regarding to sowing ratio and species matching is always preferred, a more nature friendly production system might be practiced due to decreased nitrogen fertiliser due to the nitrogen fixing capability of legumes (Serin and Erkovan, 2008), decreased herbicide utilisation (Erkovan *et al*., 2008), more efficient light absorption (Hay and Walker, 1989) and highly effective utilisation of other environmental resources (Bilgili and Acikgoz, 2011). Although, many findings are available on over yielding of mixed cropping versus sole cropping (Tukel *et al*., 2007; Erol *et al*., 2009) there are still some uncertainties about the reason, particularly with respect to the effects of legumes on cereal growth. Plant facilitates other plants especially N_2 fixing directly or actively by ameliorating harsh environmental conditions by altering soil properties or by increasing availability of resources (Kurokawa *et al*., 2010). The positive effects of legumes on companion grasses in the mixture include N_2 fixation and transfer to grasses, effective use of soil water due to different root characteristics and effective light utilisation due to different leaf anatomy (Breshears *et al*., 1997; Ludwig *et al*., 2008; Riginos *et al*., 2009). Relative frequency of facilitation and competition will inversely cause proportional gradients of ecosystem productivity (Bertness and Callaway, 1994). Between plants species there may be above ground competition for light and space, and below ground competition for water and nutrients (Mariotte *et al*., 2012).

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Complementary use of resources occurs because of advantageous interactions between mixed cropped species such as structural support for climbing which improves light interception (Keating and Carberry, 1993) effective use of the soil zone by different rooting depths and root structures (Li *et al*., 2006), transfer of fixed nitrogen from legumes to grasses (Gokkus *et al*., 1999; Koc *et al*., 2004; Mariotti *et al*., 2009) and reduced weed and pathogenic pressure owing to shading (Mitchell *et al*., 2002).

Although, competition among plants occurs both above and below ground, below ground competition can be stronger than aboveground competition (Casper and Jackson, 1997). Above ground competition involves mainly light whereas below ground competition involves a broader spectrum of resources such as water and nutrients (Rubio *et al*., 2001). While shoot architecture such as height, branching and leaf morphology plays a significant role in above ground competition (Connor *et al*., 2011), root architecture and its spatial configuration plays a significant role in below ground competition among plants (Fitter *et al*., 1991). Mariotti *et al*. (2009) reported that cereals had a higher below ground competitive ability than legumes and legumes had a higher above ground competitive ability than cereals in their mixtures and they also reported that competitive ability of the plants showed differences among the species.

Although, competitive ability changes regarding the above or below ground part of the plants, total competitive ability which is a combination of above and below ground competition can be described as lower (negative interaction), equal (no interaction) and greater (positive interaction or facilitative effect) (Cahill, 1999).

The majority of mixed cropping studies focus on yield and yield components although there are still gaps regarding the facilitative or competitive effect of mixture components. To better understand the mechanism of higher yields associated with cereal and legume mixed cropping, it is necessary to understand the total competitive ability of the mixture components. The objectives of this study were to determine the changes of above or below ground and total competitive ability of the cereals and legume mixture under different sowing ratios.

MATERIALS AND METHODS

The pot experiment was carried out under greenhouse conditions at the Faculty of Agriculture, Ataturk University, Erzurum. The seeds were sown in sand filled pots in the size of 30×30 cm on 14 November, 2011 and terminated on 11 April, 2012. The vetches were Hungarian vetch (*Vicia pannonica* cv Population) and common vetch (*Vicia sativa* cv Karaelci) while the cereals were barley (*Hordeum vulgare* cv Tokak) and oat (*Avena sativa* cv Gezkoy). A total of 4 plants were grown in each pot and each vetch was sown with every cereal in the seed proportion of 100:0, 75:25, 50:50, 25:75 and 0:100. In the sowing, two more seeds for each plant were sown and extra plants were thinned after germination. The experiment was arranged as a completely randomised design with five replications. The pots were watered regularly every 2 days with tap water. No fertilizers or pesticides were applied to the pots during the experiment.

Plant height was measured at 2 weeks intervals after emergency during the experiment. When the grasses reached the florescence stage, the plants were cut at ground level and separated into cereals and legumes. The plants were divided into leafs and stems plus spikes or florescence stalks which are referred to stems. Plant roots were separated from the soil by washing with tap water. All plants samples (stems, leafs and roots) were oven-dried at 80°C until reaching a constant weight. Total biomass was determined by weighting above and below ground parts per plant. Leaf Mass Ratio (LMR) and Stem Mass Ratio (SMR) were determined by the proportion of leaf mass and stem mass to total above ground biomass. Root Mass Ratio (RMR) was determined by the proportion of root mass to total biomass. Relative Height Growth Rate (RHGR) was determined from the plant height differences at 2 weeks intervals using the procedure followed by Ishikawa and Kachi (2000):

$$\text{RHGR} = \frac{\ln(H_2\text{-}H_1)}{(t_2\text{-}t_1)} \quad (1)$$

Where:

H_1 = The plant height at time t_1
H_2 = The plant height at time t_2

The Relative Neighbour Effect (RNE) was determined from above and below ground biomass production following equations using (Oksanen *et al*., 2006):

$$\text{RNE} = \frac{(\text{Wr-Wc})}{\max(\text{Xr, Wc})} \quad (2)$$

Where:

RNE = The Relative Neighbour Effect
Xr = The performance of manipulated plants
Xc = The performance of the controls

This index changes between +1 (facilitation) and -1 (competition) and compares the above and below ground biomass of the plants grown in the mixture to grown soil. Data was analysed statistically by analysis of variance based on the general linear model for completely randomised design using the Statview package (SAS, 1998). Multiple comparisons with Bonferroni/Dunn were used to determine the effects of sowing ratio, cereals and legumes on the RHGR, total biomass, LMR, SMR, RMR and above and below ground competition.

RESULTS

The effect of legumes on cereals: The effect of sowing ratio on RHGR was insignificant ($F_{(3, 64)} = 2.684$, p>NS). RHGR showed significant differences between cereal species ($F_{(1, 64)} = 78.199$, $p<0.0001$) although, the effect of legumes on RHGR of cereals was insignificant ($F_{(1, 64)} = 0.008$, p>NS) (Table 1). While RHGR of barley was not changed depending on the sowing ratio, it decreased in line with the increased density of oat in the mixture (Fig. 1). This different response of cereals to the sowing ratio was responsible for SR×C interaction at $p<0.01$ ($F_{(1, 64)} = 4.089$, $p<0.0040$).

Table 1: The investigated properties of the cereals grown with the vetches and results of analysis of variance

Sowing ratio	RHGR	Biomass	LMR	SMR	RMR
100C-0 L	0.269	4.338^B	37.525	17.240	45.235^A
75C-25 L	0.287	4.269^B	42.401	19.325	38.275^B
50C-50 L	0.294	4.929^B	42.344	21.205	36.452^B
25C-75 L	0.301	7.216^A	44.772	17.700	37.530^B
Average	0.288	5.188	41.761	18.868	39.373
A. sativa	0.325^A	4.992	45.884^A	17.468^B	36.649^B
H. vulgare	0.251^B	5.384	37.637^B	20.267^A	42.097^A
Average	0.288	5.188	41.761	18.868	39.373
V. pannonica	0.287	5.809^A	37.291^B	18.606	44.106^A
V. sativa	0.288	4.567^B	46.231^A	19.129	34.640^B
Average	0.288	5.188	41.761	18.868	39.373
SR×C	*	***	*	NS	*
SR×L	NS	NS	NS	NS	NS
C×L	NS	NS	NS	*	NS
SR×C×L	NS	NS	NS	NS	NS

NS: Non Significant, *$p<0.05$, **$p<0.01$, ***$p<0.001$. Means in the same column with different letters are significant

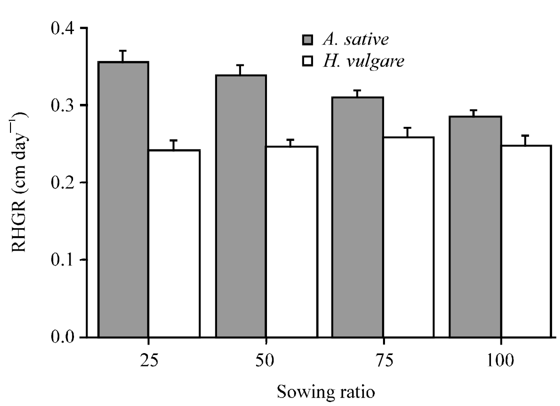

Fig. 1: RHGR of the cereals grown with the vetches at different sowing ratios (bars±1 SE)

Competition from legumes positively affected total biomass production per plant of cereals. Especially, the cereals had the highest total biomass production performance grown in the mixture of 25% cereals and 75% legumes than the other mixture combinations ($F_{(3, 64)} = 13.282$, $p<0.0001$) ($F_{(1, 64)} = 10.699$, $p<0.0017$) (Table 1). However, the density of legumes in the mixture was insignificant on total biomass production per plant of cereals. Total biomass production of oat decreased in line with increased density in the mixture whereas this relation was the opposite for barley. Hence, SR×C interaction was significant ($F_{(3, 64)} = 15.570$, $p<0.0001$) (Fig. 2).

There was a significant effect of cereals and legumes on the LMR of cereals ($F_{(1, 64)} = 19.530$, $p<0.0001$) ($F_{(1, 64)} = 22.948$, $p<0.0001$) (Table 1). The LMR of oat was higher than barley. The cereals grown with common vetch had more LMR compared to the cereals grown with Hungarian vetch. The LMR was similar in the mixture of 25% cereals and 75% legumes. The LMR of barley decreased linearly as the sowing ratio increased whereas it was higher at 75 and 100% sowing ratio than the other sowing ratio for oat. This different response to the sowing ratio between cereals caused SR×C interaction ($F_{(3, 64)} = 6.002$, $p<0.0011$) (Fig. 3).

Neither sowing ratio nor legume species had a significant effect on the SMR of cereals although barley had higher SMR than oat in the experiment (Table 1). While the oat grown with Hungarian vetch produced higher SMR, barley had higher SMR when it was grown together common vetch. This difference of cereals in response to legume was responsible for C×L interaction for SMR ($F_{(1, 64)} = 9.672$, $p<0.0028$) (Fig. 4). Competition from legumes negatively affected the below ground production of cereals ($F_{(3, 64)} = 3.685$, $p<0.0164$) ($F_{(1, 64)} = 6.908$, $p<0.0107$) ($F_{(1, 64)} = 20.851$, $p<0.0001$)

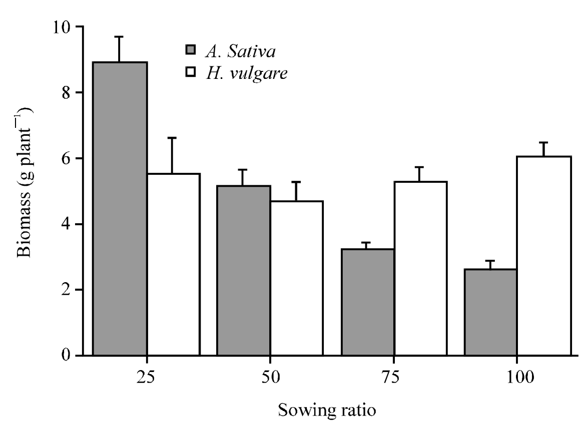

Fig. 2: Total biomass production of the cereals grown with the vetches at different sowing ratios (bars±1 SE)

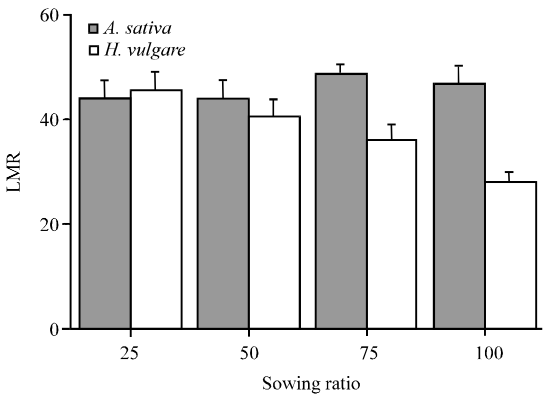

Fig. 3: LMR of the cereals grown with the vetches at different sowing ratios (bars±1 SE)

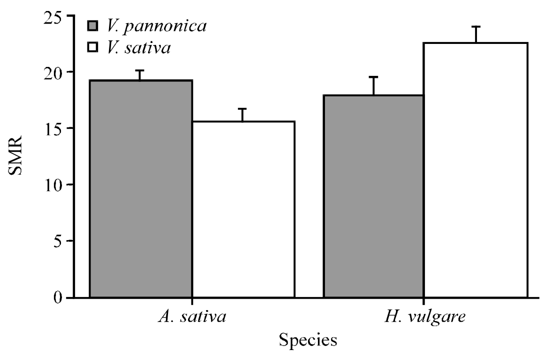

Fig. 4: SMR of the cereals grown with common or Hungarian vetches (bars±1 SE)

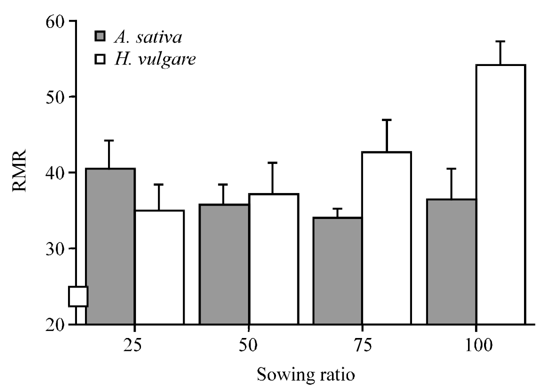

Fig. 5: RMR of the cereals grown with the vetches at different sowing ratios (bars±1 SE)

(Table 1) because sole cereal stands produced more RMR than cereals grown in mixture stands ($F_{(1,\ 64)}$ = 3.651, p<0.0170) (Fig. 5). However, the effect of mixture combinations on the RMR of cereal was insignificant. Barley had higher RMR than oat. The cereals grown with Hungarian vetch had higher RMR than plants grown with common vetch.

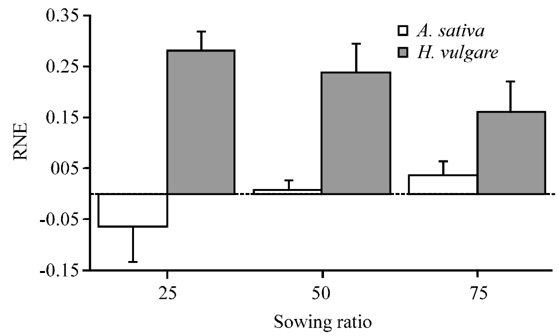

Fig. 6: Relative neighbour effects of the vetches at different sowing ratios in the mixture on above ground competition of the cereals (bars±1 SE)

Table 2: Relative neighbour effect of the vetches at different sowing ratio on the cereals and results of analysis of variance

Sowing ratio	Above	Below
75C-25 L	0.107	- 0.150
50C-50 L	0.122	- 0.170
25C-75 L	0.100	- 0.137
Average	0.110	- 0.152
A. sativa	- 0.006[B]	- 0.009[A]
H. vulgare	0.225[A]	- 0.295[B]
Average	0.110	- 0.152
V. pannonica	0.084	- 0.118
V. sativa	0.135	- 0.186
Average	0.110	- 0.152
SR×C	*	NS
SR×L	NS	NS
C×L	***	***
SR×C×L	NS	NS

NS: Non Significant, *p<0.05, **p<0.01, ***p<0.001. Means in the same column with different letters are significant

According to the RNE results, the cereals were facilitatively affected by the vetches with respect to the above ground production althouh it was competitive with respect to the below ground production under mixed cropping condition. Neither above nor below ground production were affected by different sowing ratios ($F_{(2,\ 48)}$ = 0.181, p>NS) ($F_{(2,\ 48)}$ = 0.182, p>NS) (Table 2). The vetches had a competitive effect on oat whereas it had a facilitative effect on barley with respect to the above ground production although, the effect of vetches on below ground production was competitive in both cereal species ($F_{(1,\ 48)}$ = 57.126, p<0.0001) ($F_{(1,\ 48)}$ = 39.341, p<0.0001) (Table 2). The RNE of vetches on barley decreased regularly with increasing its density in the mixture whereas it increased in oat at line with the increasing plant density in the mixture. This different response of cereal species to the sowing ratio with respect to RNE caused SR×C interaction ($F_{(2,\ 48)}$ = 4.178, p<0.0213) (Fig. 6). Hungarian vetch affected facilitatively the above ground production of both cereals although common vetch suppressed the above ground production

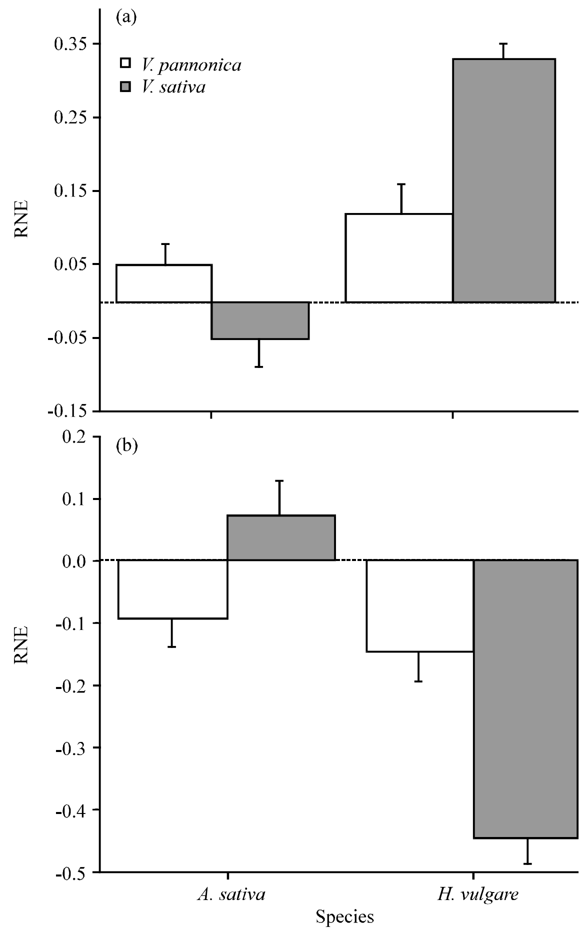

Fig. 7: Relative neighbour effect of the vetches on a) above and b) below ground competition of the cereals (bars±1 SE)

of oat but facilitated the above ground production of barley ($F_{(1, 48)} = 28.280$, $p<0.0001$) (Fig. 7a). The effect of vetches was opposite to the below ground production of cereals compared to the above ground competition ($F_{(1, 48)} = 26.050$, $p<0.0001$) (Fig. 7b).

The effect of cereals on legumes: The effect of the sowing ratio on the RHGR of vetches was insignificant ($F_{(3, 64)} = 0.203$, $p<0.8941$). The RHGR of vetches did not change significantly between species ($F_{(1, 64)} = 3.109$, $p<0.0827$). The vetches grown with barley had higher RHGR than those grown in oat mixtures ($F_{(1, 64)} = 4.993$, $p<0.0289$) (Table 3). The RHGR of Hungarian vetch was slightly higher in oat mixtures whereas the RHGR of common vetch was higher in barley mixtures. Therefore, L×C interaction was statistically significant ($F_{(1, 64)} = 15.017$, $p<0.0003$) (Fig. 8).

The effect of the sowing ratio, vetches and cereals on total biomass production of vetches was significant

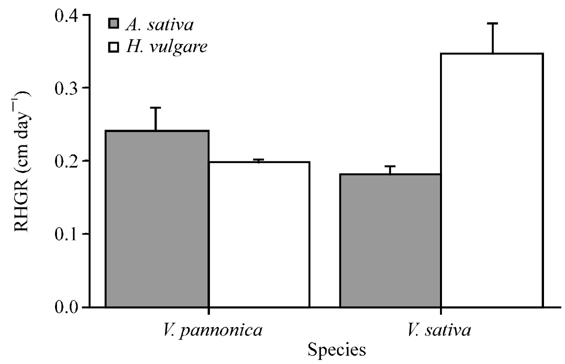

Fig. 8: The RHGR of the vetches grown with barley or oat (bars±1 SE)

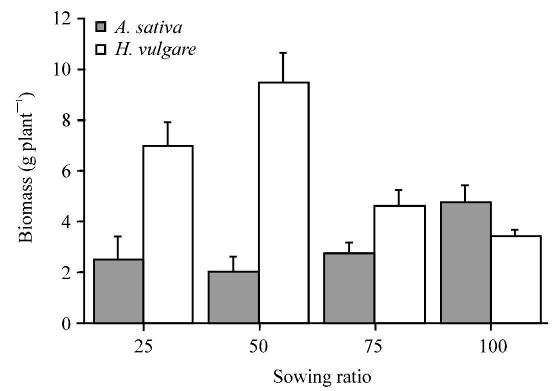

Fig. 9: Total biomass of the vetches grown with the cereals at different sowing ratios (bars±1 SE)

($F_{(3, 64)} = 4.418$, $p<0.0069$) ($F_{(1, 64)} = 4.304$, $p<0.0421$) ($F_{(1, 64)} = 50.760$, $p<0.0001$) (Table 3). Vetches produced more total biomass including 50% cereal in the mixture than in the other mixture combinations. The lowest total biomass production of vetches was recorded in the mixture stands containing 75% cereals. Common vetch produced 4.96 g plant^{-1} total biomass while Hungarian vetch produced 4.05 g plant^{-1} total biomass. This different total biomass production capacity between vetches was statistically significant. Vetches grown in companion with barley produced more total biomass compared to the plant grown with oat companion. Vetches grown in the mixture of 25 or 50% barley produced more total biomass than the other mixture combination whereas, the highest total biomass was recorded pure stands in oat mixture combinations. Hence, SR×C interaction was significant ($F_{(3, 64)} = 18.658$, $p<0.0001$) (Fig. 9). Hungarian vetch had similar total biomass production while common vetch produce more total biomass grown in companion with barley. This different response to mixture component between vetches was responsible for L×C interaction ($F_{(1, 64)} = 33.768$, $p<0.0001$) (Fig. 10).

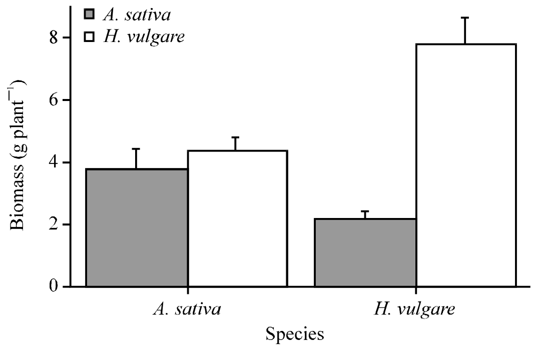

Fig. 10: Total biomass of the vetches grown with barley or oat (bars±1 SE)

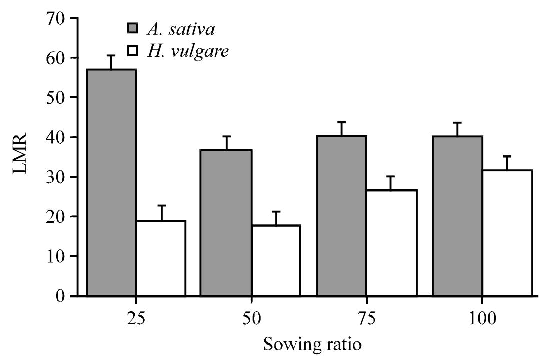

Fig. 11: LMR of the vetches grown with the cereals at different sowing ratios (bars±1 SE)

Table 3: The investigated properties of the vetches grown with the cereals and results of analysis of variance

Sowing ratio	RHGR	Biomass	LMR	SMR	RMR
100L-0C	0.233	4.003^{AB}	36.248^{A}	24.273	39.479^{B}
75L-25C	0.231	3.620^{B}	33.864^{A}	22.018	44.118^{AB}
50L-50C	0.246	5.705^{A}	27.433^{B}	18.515	54.050^{A}
25L-75C	0.257	4.690^{A}	37.852^{A}	18.575	43.575^{AB}
Average	0.242	4.505	33.850	20.845	45.306
V. pannonica	0.218	4.053^{B}	31.167^{B}	19.335	49.499^{A}
V. sativa	0.265	4.956^{A}	36.532^{A}	22.355	41.112^{B}
Average	0.242	4.505	33.850	20.845	45.306
A. sativa	0.212^{B}	2.955^{B}	43.722^{A}	22.073	34.205^{B}
H. vulgare	0.271^{A}	6.054^{A}	23.977^{B}	19.617	56.406^{A}
Average	0.242	4.505	33.850	20.845	45.306
SR×L	NS	NS	NS	NS	NS
SR×C	NS	***	***	*	**
L×C	**	***	**	NS	NS
SR×L×C	NS	NS	NS	NS	NS

NS: Non Significant, *p<0.05, **p<0.01, ***p<0.001. Means in the same column with different letters are significant

The sowing ratio, vetches and cereals strongly affected LMR ($F_{(3, 64)} = 4.563$, $p<0.0059$) ($F_{(1, 64)} = 6.260$, $p<0.0144$) ($F_{(1, 64)} = 84.799$, $p<0.0001$). The LMR of vetches was lower at a mixture of 50% cereals and 50% vetches than the other mixture combinations (Table 3). The LMR of common vetch was higher than Hungarian vetch. The legumes grown in a mixture with oat had higher LMR than those grown with barley. The highest LMR of vetches

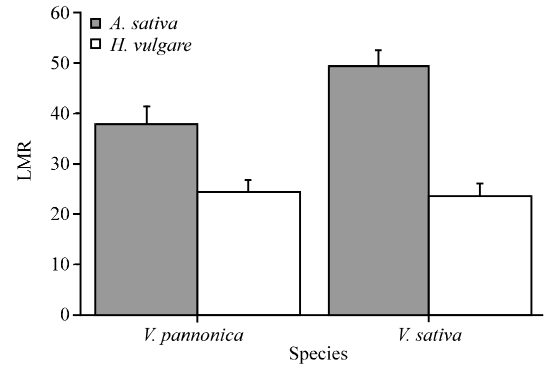

Fig. 12: LMR of the vetches grown with barley or oat (bars±1 SE)

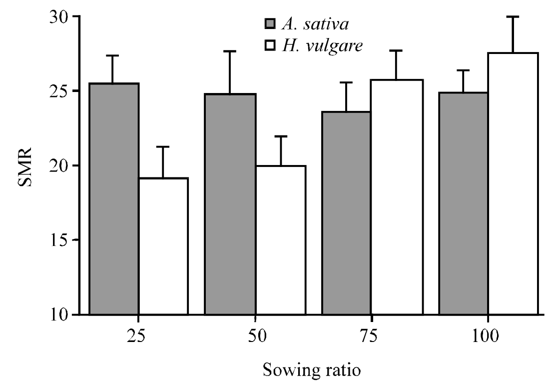

Fig. 13: SMR of the vetches grown with the cereals at different sowing ratios (bars±1 SE)

was recorded in the mixture containing 25% oat thereafter it decreased whereas higher LMR was recorded for vetches grown with high intensity barley containing mixture combinations. This different response of different mixture application to sowing ratio caused SR×C interaction for LMR ($F_{(3, 64)} = 8.780$, $p<0.0001$) (Fig. 11). Vetches had similar LMR when grown with barley whereas common vetch had higher LMR than Hungarian vetch when grown with oat. This difference in LMR between legumes was responsible for L×C interaction ($F_{(1, 64)} = 8.409$, $p<0.0051$) (Fig. 12).

The effect of sowing ratio, vetches and cereals on SMR of legumes was not significant although there was significant interaction between SR and C with respect to SMR (Table 3). SMR did not change with the sowing ratio in the mixture with oat although the SMR of vetches increased in the mixture containing 50% or more barley. This different response of species with respect to SMR caused SR×C interaction ($F_{(3, 64)} = 3.799$, $p<0.0143$) (Fig. 13).

Below ground competition with cereals increased the RMR of vetches (Table 3). The effect of sowing ratio,

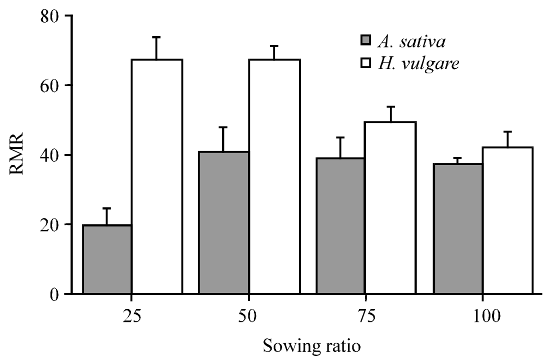

Fig. 14: RMR of the vetches grown with the cereals at different sowing ratios (bars±1 SE)

Table 4: Relative neighbour effect of the cereals at different sowing ratio on the vetches and results of analysis of variance

Sowing ratio	Above	Below
75C-25 L	-0.128	-0.076
50C-50 L	-0.261	0.166
25C-75 L	-0.099	0.035
Average	-0.163	0.042
V. pannonica	-0.192	0.105
V. sativa	-0.133	-0.022
Average	-0.163	0.042
A. sativa	0.012^{A}	-0.177^{B}
H. vulgare	-0.337^{B}	0.260^{A}
Average	-0.163	0.042
SR×L	NS	NS
SR×C	**	**
L×C	NS	*
SR×L×C	NS	NS

NS: Non-Significant, *: p<0.05, **: p<0.01, ***: p<0.001. Means in the same column with different letters are significant

vetches and cereals were significant ($F_{(3,\ 64)}$ = 3.231, p<0.0280) ($F_{(1,\ 64)}$ = 5.539, p<0.0176) ($F_{(1,\ 64)}$ = 41.620, p<0.0001). Vetches grown with a 50% cereals component had higher RMR than the other mixture combination or sole sowing. Hungarian vetch had more RMR than common vetch. Vetches grown in the mixture containing 25% oat had lower RMR than the other sowing combinations whereas it was similar and higher in the mixture with 25 or 50% barley than the other sowing combinations. This difference in the RMR of vetches in response to the sowing ratio was responsible for SR×C interaction ($F_{(3, 64)}$ = 7.577, p<0.0002) (Fig. 14).

The RNE on above and below ground production of vetches did not change significantly depending on the sowing ratio and vetch species, although it was affected significantly by cereal species ($F_{(1, 48)}$ = 30.230, p<0.0001), ($F_{(1, 48)}$ = 28.965, p<0.0001) (Table 4). The RNE on vetches was positive with respect to below ground production although it was negative with respect to aboveground production. Vetches grown with oat always had more facilitation effect than those grown with barley. The decreases in above ground production were lower for

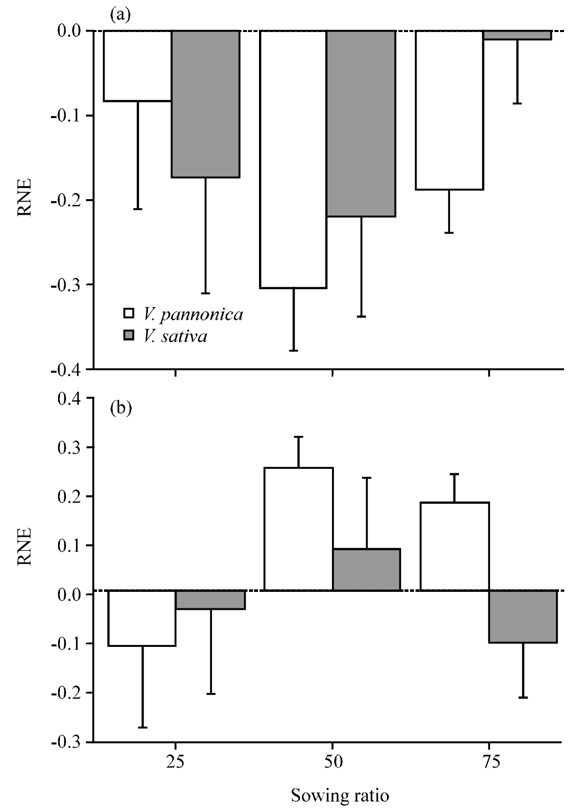

Fig. 15: Relative neighbour effects of the cereals at different sowing ratios in the mixture on a) above b) below ground competition of the vetches (bars±1 SE)

Hungarian vetch grown in mixtures containing 25% cereal although it was higher than common vetch grown in the mixture with a higher percentage of cereals. Hence, SR×C interaction was significant for RNE ($F_{(3,\ 48)}$ = 6.315, p<0.0009) (Fig. 15a). Below ground production of vetches grown at the mixture they attaining 25% suppressed by cereals but this effect reversed when mixture containing 50% vetches. Conversely, when the vetch ratio was 75% in the mixture below ground production competed in common vetch and facilitated in Hungarian vetch by cereals.

Overall SR×C interaction was significant ($F_{(3, 48)}$ = 5.243, p<0.0075) (Fig. 15b). Below ground production of vetches was affected negatively by oat although this negative effect was more pronounced in common vetch whereas the effects of barley on below ground production of vetches was facilitated and similar for both species.

This different effect of cereals below ground production of vetches was responsible for L×C interaction ($F_{(1, 48)}$ = 5.495, p<0.0213) (Fig. 16).

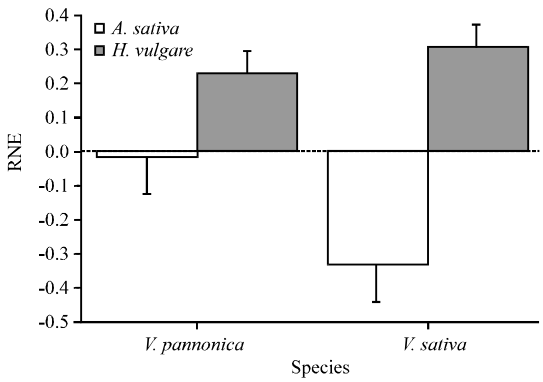

Fig. 16: Relative neighbour effect of the cereals on below ground competition of vetches (bars±1 SE)

DISCUSSION

Mixed cropping is a widespread practice especially in temperate climates which is based on the facilitative effect of components to increase production per unit area. If mixture establishes suitable complementary species with proper sowing design, the stand will always be more productive than sole cropping of the component. The igh yielding capacity of mixture over sole cropping of component have been reported by Ofori and Stern (1987), Gokkus *et al*. (1999), Koc *et al*. (2004), Ayub *et al*. (2008) and Mariotti *et al*. (2009). Higher yields result from more effective use of resources owing to different leaf anatomy, efficient light interception (Hay and Walker, 1989) and root architecture, efficient rhizosphere utilisation (Hauggaard-Nielsen *et al*., 2001; Li *et al*., 2006) or facilitative interaction between components (Hauggaard-Nielsen and Jensen, 2005; Uzun and Asik, 2012). The sowing ratio of the component plant in the mixture is crucially important to yield performance and it changes depending on the plant and environment (Ofori and Stern, 1987). Therefore, the interactions related to the sowing ratio at the investigated parameters were significant in the experiment (Table 1 and 2).

In the study, there was no beneficial effect of the vetches on the RHGR of barley because the barley grown solely had similar RHGR to that grown in a mixture with different sowing ratios although oat showed better RHGR when it was grown in the mixture of 25 or 50% sowing ratio with the vetches. Hence, it can be stated that Hungarian and common vetch had a neutral effect on the RHGR of barley although positive effect on oat's RHGR when oat had half or a lower percentage share in the mixture. The vetches grown with barley had higher RHGR compared to those grown with oat (Fig. 8). Oat should have higher below ground competition ability than barley because below ground competition causes a decrease in the shoot growth of legumes (Mariotti *et al*., 2009). Since, barley had a neutral or negative below ground competitive effect on common vetch, common vetch had higher RHGR than that grown with oat. Different competitive effects between the vetches and cereals were reported by several researchers (Lithourgidis *et al*., 2006; Tukel *et al*., 2007; Erol *et al*., 2009; Mariotti *et al*., 2009).

The cereals sown with Hungarian vetch produced more total biomass than those grown with common vetch. Especially, oat produced the highest total biomass per plant when grown with 75% of the vetches. As the sowing ratio of oats increased, total biomass of oat per plant decreased. The competitive ability of companion plants change depending on the sowing ratio in the mixture (Lithourgidis *et al*., 2006). Especially, if intraspecific competition is lower than interspecific competition between mixture components, higher yield can be enhanced in the component plant (Vandermeer, 1990). In additional to the facilitative advantage, some amounts of symbiotically fixed nitrogen by legumes are transferred to cereals in their mixtures (Xiao *et al*., 2004; Erkovan *et al*., 2008) and this causes an extra production performance in cereals (Mariotti *et al*., 2009). At least one or more of the foregoing statements may be responsible for the higher total biomass production of oat in oat-vetch mixture at the 25:75 seeding ratio which also caused SR×C interaction.

The results showed that there was no positive effect of cereals on total biomass production of Hungarian vetch, although, common vetch grown with barley produced higher total biomass than that grown with oat. The reason for this should be originated from higher above ground competitive ability of common vetch across barley because legumes produce more above ground biomass under mixed cropping conditions when they had higher above ground competitive ability (Mariotti *et al*., 2009). SR×L interaction also implied that if a barley-vetches mixture is established at 50:50 sowing ratio, it could give the best results with respect to total biomass production per plant in vetches.

The higher LMR of oat than barley is related to the plant characteristics because the breeding aim is different from each other in the cereals used in the experiment. The main cultivating aim of oat (Gezkoy) is hay production whereas the main cultivating aim of barley (Tokak) is to grain production (Tan and Serin, 1996). The reason for higher the LMR production of the cereals grown with common vetch might be related to the competitive ability and nitrogen transfer from legumes to cereals because the plants compete with the other plants in mixture for light can produce more leafs than pure stands (Ofori and Stern, 1987; Keating and Carberry, 1993). In line with the increasing sowing ratio in the mixture, the LMR of oat decreased while it increased in barley. This situation might be originated from differences in the competition ability of the species. An opposite of LMR, barley had higher SMR than oat. This was a result of the differences in assimilate partition in the above ground part of the cereal species originated characteristics.

The vetches sown with 50% cereals in the mixture had lower LMR than the other sowing ratio owing to the increasing RMR of the vetches. In cereal-legume mixtures below ground competition causes increases in the root production of legumes while it causes increases in the shoot production of cereals (Mariotti *et al*., 2009). According to the results, below ground competition severity increase when a cereal and legume mixture is established with the sowing ratio of 50:50. Changes in leaf production dependant on the sowing ratio were also reported by Alemu *et al.* (2007) in oat-vetch mixtures. The vetches grown with oat in the mixture had higher LMR than those grown with barley. This situation may be related to the leaf area of the component plant because oat had more leaf area than barley. Conversely, the observed higher LMR of common vetch when grown with barley can be originated from differences of competitive ability of common vetch across cereal species. Different competitive response of legumes across cereals was reported by other researchers (Alemu *et al*., 2007; Tukel *et al*., 2007).

The differences with respect to LMR between vetch species might be related to their plant characteristics. Higher LMR production of vetches grown with oat in the mixture can be the facilitative effect of cereal on the above ground production of legumes stemmed from below ground competition because the decreasing below ground competition in cereals-legumes mixture prompts the above ground production of legumes. In additional to below ground competition, legumes had a higher competitive ability than cereals in intercropping systems owing to their climbing grown habits (Mariotti *et al*., 2009). The vetches showed different responses to the changing sowing ratio of cereals in the mixture with respect to LMR. This situation stemmed from the changing competitive ability across cereals under different sowing ratios. Similar results were also reported by Dhima *et al.* (2007) and Tukel *et al.* (2007).

As the barley sowing rate decreased in the mixture the SMR of vetches increased, especially after 50% of barley in the mixture. This result implied that a higher vetch ratio in the mixture has a suppressive effect on barley owing to the higher competitive ability of vetches across barley. The main reason for this suppressive effect should be originated from the higher intraspecific competitive ability of vetches across barley than intraspecific competitive ability because higher yields have been reported when interspecific competition between the two species of the mixture was lower than intraspecific competition (Vandermeer, 1990).

The SMR of the vetches did not changed significantly at different sowing ratios when grown with oat, although the vetches grown alone or in a mixture with barley at the sowing ratio of 75% vetches produced higher SMR owing to increased above ground production. The results reveal that common vetch had a suppressive effect on barley when its proportion was higher than 50% in the mixture. Similar results were also reported by Dhima *et al.* (2007).

Competition between cereals and vetches caused a changing assimilate allocation pattern and more assimilate allocation for shoot growth in cereals under competition conditions, whereas legumes allocate more assimilation for root growth (Mariotti *et al*., 2009). Hence, sole sown cereals produced more below ground biomass than the cereals grown in the mixture although the vetches showed opposite attributes to cereals in the experiment. The differences in the RMR of the vetches and cereals species should be related to the differences of their plant response in competition conditions because assimilate allocation pattern in barley changed significantly depending on the varying sowing density and it showed a decreasing trend in line with the increased vetches ratio in the mixture. This also caused SR×C interaction. The cereals grown with Hungarian vetch produced more RMR than those grown with common vetch. In the vetches those grown with barley had higher RMR than those grown with oat. These differences could be originated from the higher competitive ability of common vetch than Hungarian vetch across cereals because more assimilate translocation to root ocurred in the cereals grown with Hungarian vetch and more assimilate translocation to root in the vetches when grown with barley (Fig. 14).

The general picture of RNE showed that oat was not affected by vetches competition although barley grown with common vetch was seriously affected. Competition and facilitation plays an important role on the structure and dynamics of plant-plant interactions. It can switch from competitive to facilitative or from facilitative to competitive within the plant lifecycle (Espeland, 2013). The impact of competition or facilitation depends on annual or perennial plants species because direct competition among plant species is due to either space or resources (Hatipoglu and Tukel, 1997; Kurokawa *et al*., 2010). The balance between competition and facilitation can change over plants' growth history and their stress conditions. Different plant species could have greater competitive or facilitative consequences in different sowing ratios. Decreasing plant density often shifts the plant-plant interaction from competitive to facilitative during growing seasons. Barley allocate more assimilation to shoot growth and increased above ground production when grown with common vetch whereas assimilate allocation to root growth decreased seriously and below ground production decreased significantly. In addition, competition may be responsible for the increases in reproductive organ number such as leafs and roots (Kikvidze *et al*., 2001). Conversely, higher growth plants more easily suppress less grown plants in the mixture. Since, cereals had higher growth characteristics than the vetches, above ground production of the vetches was negatively affected by cereals (Table 4). The more suppressive effect of the cereals on above ground production of the vetches occurred at the 50:50 sowing ratio. These suppressive effects of companion crops change depending on the sowing ratio (Mariotte *et al*., 2012). Therefore, the more suppressive effect of cereals on the vetches occurred at the 50:50 sowing ratio in the experiment. This result interpreted that the 50:50 sowing ratio gives the best result for vetch growing. Similar results were also recorded for oat although the effects did not pronounce as is in barley. According to the results the cereals had a more pronounced facilitative effect on the vetches at the 50:50 sowing ratio. These results showed that common vetch had a facilitative effect on the above ground production of barley although, a competitive effect on the below ground production of both cereals. A similar result was also reported by other researchers (Kikvidze *et al*., 2001; Espeland, 2013).

CONCLUSION

Oat with a 25% sowing ratio in the mixture produced higher total biomass than a sole or higher sowing ratio whereas barley was not seriously affected by the sowing ratio although the assimilate allocation pattern changed significantly depending on the companion crop and sowing ratio in cereals. As the sowing density of barley increased in the mixture assimilate allocation to roots increased whereas it was not changed seriously in oat. Hungarian vetch positively affected above ground production of both cereal species although common vetch had a negative effect on above ground biomass production of oat and a positive effect on barley. Below ground production of barley decreased significantly when grown with common vetch. Total biomass production of common vetch increased significantly when grown with barley. Vetches grown with barley at the sowing ratio of <50% produced more total biomass whereas sole grown vetches produced more total biomass when grown with oat. These results showed that the suppressive effect of oat on vetches increases as the oat ratio increases in the mixture especially on the below ground production of companion legumes although common vetch had a facilitative effect on barley. Especially, root growth of common vetch was not affected by competition. Below ground biomass production of the companion legumes is important for biological nitrogen fixation because biological nitrogen fixation is directly related to assimilate translocation to roots in legumes (Breshears *et al*., 1997; Xiao *et al*., 2004; Serin and Erkovan, 2008; Erkovan *et al*., 2008). This is a desirable situation for environmentally friendly crop production practices. Finally, a common vetch-barley mixture can be preferred in spring sowing in winter cold hazard problem areas, although the sowing ratio of common vetch in a mixture with barley should not be over 50%.

ACKNOWLEDGEMENTS

Researchers would like to thank Prof. Dr. Kamil Haliloglu, Department of Field Crops for his critical review and comments about the manuscript. Part of this study was submitted as an undergraduate thesis by Ummuhan Oz, M. Mustafa Birben and Ridvan Tunc at the spring term of 2012.

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