Nitrogen uptake and its efficiency in triticale (*Triticosecale* Witt.) – field beans (*Vicia faba* var. *minor* L.) intercrop

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ABSTRACT

A field experiment of split-plot design was conducted in 1999 and 2000 on light soil to study the effect of different levels of mineral nitrogen fertilization: 0, 25 and 50 kg N/ha on dry matter yield, N uptake and N efficiency indices of spring triticale and field beans grown in pure stands and in intercrop. The intercrop was composed using half of the seeding densities from pure stands. Intercropping increased protein content in grain and plant biomass of triticale irrespective of N input. Increasing N rate from 0 to 25 kg/ha increased plant biomass yield of triticale and intercrop. Nitrogen uptake with grain and biomass of intercrop was significantly higher than by sole crops showing partial complementarity in N use by intercropped species despite strong dominance of triticale over field beans. The higher the N fertilizer rate, the lower was the gain from intercropping mainly due to increased suppression of field beans by triticale. Agronomic efficiency was similar for triticale and intercrop but it was significantly smaller for field beans indicating there were other limited resources hampering growth of the legume.

Keywords: intercrop; nitrogen fertilization; triticale; field beans

Growing two crops together in the same field as an intercrop (mixture) is a common practice in some regions of the world, mainly in the tropics where traditional farming methods still prevail (Fukai 1993). On the contrary, intercrops are not widespread in industrial agriculture focused on sole crops, which are easier to manage, and well supplied with modern detailed technologies of production mainly to maximize yield (Anil et al. 1998). During the past decade industrial agriculture was criticized for excessive use of external inputs and its danger to environmental degradation (Altieri 1999). Intercropping may be one of many steps towards making agriculture more sustainable humanly active. Jolliffe (1997) showed that plant mixtures are on the average 12–13% more productive than pure stands. A large part of the gain is due to resource complementarity phenomenon that occurs when intercrop components acquire limiting resources from different above- or belowground space, at different times or utilize different forms of the resources (Bulson et al. 1997). The process is anticipated in the legume-nonlegume intercrop. Legume component fixes atmospheric nitrogen and this results in a decrease of plant competition for soil N between the species and reduces demand for fertilizer N. According to Danso et al. (1987), 92% of the N in field beans intercropped with barley was derived from the symbiotic fixation. Thus one of the problems of intercropping legumes with cereals is a proper choice for the nitrogen fertilizer rate. Reynolds et al. (1994) found that N-fixing legumes could be successfully intercropped with wheat at suboptimal levels of N input without detriment to wheat yields.

Some experiments showed an advantage of field beans – spring wheat intercrop over pure stands of the species (Bulson et al. 1997, Haymes and Lee 1999) regardless of nitrogen input. Other research was focused on N fixation mechanism in intercrops of field beans with spring cereals (Danso et al. 1987, Cochran and Schlentner 1995). Little data is available on the effects of fertilizer nitrogen rates on yields and nitrogen efficiency in the intercrop. In the experiments of Ghanbari-Bonjar and Lee (2002) the optimum rate of nitrogen fertilizer for field beans – wheat forage production was 75 kg N/ha, however relative gain from intecropping in terms of LER (land equivalent ratio) was the highest without added nitrogen. Management of nitrogen fertilizer also affects competitive interactions between components of an intercrop. Martin and Snaydon (1982) reported that an application of N fertilizer increased root competitive ability of barley intercropped with field beans, and when the only roots of the two

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species grown together N input caused reduction in relative yield total.

Field bean cultivars of determinate growth form are more similar to spring triticale at the time of reaching full maturity than conventional ones and this facilitates mechanical harvest of the intercrop for grain. However triticale is better adapted to an unproductive environment of sandy soil. In the intercrop, low N external input should partially level out the difference without a decrease in yield of the two species. The objective of the research was to determine the effect of nitrogen fertilizer rates on the performance of field beans – spring triticale intercrop in terms of plant biomass yield, nitrogen uptake and nitrogen efficiency.

MATERIAL AND METHODS

The experiment was conducted on sandy loam soil (15–20% clay and silt) in 1999 and 2000 at the Experimental Station of Agricultural University of Wroclaw, Poland. Spring triticale and field beans (fababean) were grown in pure stands and in a mixture with three nitrogen fertilizer rates: 0, 25 and 50 kg N/ha with four replicates. This formed a split-plot design with N rates as a main plot and the type of cropping as a subplot. The area of each plot was 35 m^2. Potato fertilized with farm manure was grown in the field each year before the experiment. During seedbed preparation in spring the field was fertilized with mineral phosphorus, 30 kg P/ha as superphosphate and potassium, 75 kg K/ha as potassium salt. Spring triticale, field beans and a mixture of the two species were sown 31 March 1999 and 6 April 2000 at a rate of 500, 90 and 250 + 45 viable seeds/m^2, respectively. Intercrop was sown in two passes with the seeder, the first one with seeds of field beans. Inorganic N was applied to the main plots just after sowing of crops as urea (46% N). Weeds were controlled each year in all plots with herbicide Basagran 480SL (bentazon) at a rate of 1.5 l/ha when field beans were 10 cm tall and triticale was at tillering stage. Plant samples were taken at full maturity of the crops from 0.5 m^2 area of each plot to determine the yield components of the species and the percentage of the species in the intercrop. The experiment was harvested with the combine harvester. Grain yield and yield components of the two species were presented elsewhere (Sobkowicz and Parylak 2002). Subsamples of grain and straw of the species were taken to estimate the content of dry matter. Plant nitrogen was determined in grain and plant biomass (grain dry matter yield + straw dry matter yield) in two replicates using Kjeldahl's method based on treatment mean samples of each species. Protein content was calculated using N × 6.25 formula. Nitrogen uptake was determined multiplying treatment-mean grain and plant biomass nitrogen with grain and biomass dry matter yield, respectively, of each species from each plot. The benefit from intercropping was estimated using a land equivalent ratio (LER) (Mead and Willey 1980):

$$LER = (Y_{tb}/Y_{tt}) + (Y_{bt}/Y_{bb})$$

where: Y_{tb} is the yield of triticale in intercrop, Y_{tt} is the yield of triticale in pure stand, Y_{bt} is the

Table 1. Protein content in plants in % d.m. (mean 1999–2000)

Nitrogen rate (kg/ha)	Cropping method	Triticale		Field beans	
		grain	plant biomass	grain	plant biomass
0	pure stand	11.4	6.8	28.3	13.2
	intercrop	11.8	7.2	28.1	13.2
25	pure stand	11.1	6.4	27.9	13.0
	intercrop	12.0	7.0	28.9	13.6
50	pure stand	11.1	6.4	28.1	13.4
	intercrop	12.1	7.2	29.5	13.3
0		11.6	7.0	28.2	13.2
25		11.6	6.7	28.4	13.3
50		11.6	6.8	28.8	13.4
	pure stand	11.2	6.5	28.1	13.2
	intercrop	12.0	7.1	28.8	13.4

yield of field beans in intercrop, Y_{bb} is the yield of field beans in pure stand. LER is an area of the land under pure stands giving the same amount of yield of each species as the unit area of the intercrop. Land equivalent ratio > 1.0 means a gain from intercropping. The ratio was calculated for plant biomass yield and nitrogen uptake with plant biomass and grain. To assess nitrogen efficiency the following indices were calculated (Delogu et al. 1998):

1. NHI – nitrogen harvest index, as the ratio of N uptake with grain to total N uptake (with plant biomass)
2. NUE – nitrogen utilization efficiency, as the ratio of grain yield to total N uptake
3. AE – agronomic efficiency, as the ratio of (grain yield at N_x – grain yield at N_0) to applied N at N_x
4. RF – apparent recovery fraction, as the ratio of (total N uptake at N_x – total N uptake at N_0) to applied N at N_x, where N_0 is 0 N/ha and N_x is 25 or 50 kg N/ha

The nitrogen harvest index and nitrogen utilization efficiency was calculated per species yield basis in pure stand and in mixture because the response of each species was the main interest in the experiment. Other nitrogen indices were calculated per species in pure stand and per mixture as a whole because in the equations they use N fertilizer rate applied per unit area. Most data was subjected to analysis of variance and means were compared using Tukey's honestly significant difference test (*HSD*).

RESULTS

Intercropping increased protein content in grain and aboveground plant biomass of each species irrespective of nitrogen fertilization rate (Table 1). The increases were: 0.8 and 0.6% for grain and biomass of triticale, respectively, and 0.7 and 0.2% for grain and biomass of field beans. Increased N fertilizer rate from 0 to 50 kg/ha increased protein content in grain of field beans by 0.6%. There was no change in grain protein content of triticale due to different rates of N fertilization and only small changes in plant biomass protein content of both species.

Dry matter yields of the two species were small indicating that the environment of the light soil

Table 2. Yields (mean 1999–2000)

Nitrogen rate (kg/ha)	Cropping method	Plant biomass (t d.m./ha)	N uptake (kg/ha)	
			grain	plant biomass
	triticale	5.94	51	63
0	field beans	3.12	44	62
	intercrop	5.83	60	79
	triticale	7.74	62	77
25	field beans	3.96	54	78
	intercrop	7.04	73	92
	triticale	8.70	68	87
50	field beans	3.98	61	82
	intercrop	7.81	76	100
0		4.96	52	68
25		6.25	63	83
50		6.83	68	90
	triticale	7.46	60	76
	field beans	3.69	53	74
	intercrop	6.89	70	90
$HSD_{0.05}$ – nitrogen rate		0.69	9	12
$HSD_{0.05}$ – cropping method		0.55	5	8
$HSD_{0.05}$ – interaction		1.01	n.s.	n.s.

Table 3. Land equivalent ratio (mean 1999–2000)

Yield	Relative yield	Nitrogen rate (kg/ha)			Mean
		0	25	50	
Plant biomass dry matter	triticale	0.75	0.75	0.78	0.76
	field beans	0.44	0.31	0.27	0.34
	LER	1.19	1.06	1.05	1.10
Grain N	triticale	0.80	0.85	0.89	0.84
	field beans	0.43	0.39	0.25	0.36
	LER	1.23	1.24	1.14	1.20
Plant biomass N	triticale	0.80	0.84	0.89	0.84
	field beans	0.46	0.36	0.28	0.37
	LER	1.26	1.20	1.17	1.21

was unproductive although triticale gave two times greater yield than field beans and also 8.3% significantly greater yield than the intercrop (Table 2). There was a significant interaction between the type of cropping and yielding under different N input. Increasing the fertilizer rate from 0 to 25 kg/ha increased significantly the plant biomass yield of triticale and the mixture by 30.3 and 20.8%, respectively, but the yields did not change when the N rate was increased from 25 until 50 kg/ha. Dry matter yields of field beans were unaffected by varying nitrogen input. On the average, increasing the N rate from 0 to 25 kg/ha produced 26% increase in dry matter yield in the experiment.

Compared to 0 N kg/ha treatment, nitrogen rate of 25 kg/ha increased significantly the N uptake with grain and biomass of crops but there was no further increase in N uptake with 50 kg N/ha. Unlike dry matter yields, significantly highest nitrogen uptake in the experiment was recorded for grain and biomass of the mixture indicating a clear benefit from intercropping. Nitrogen uptake with grain of the mixture was significantly 16.7% higher than with grain of triticale and 32.0% higher than with the grain of field beans. Nitrogen uptake with plant biomass of the mixture was 18.4% higher than with the biomass of triticale and 21.6% higher than with the biomass of field beans.

Triticale out competed field beans in the intercrop because relative yield of dry matter of triticale and relative N uptake were higher than those for the legume (Table 3). On the average intercropped triticale produced 76% of pure stand dry matter yield while field beans only 34%. Nevertheless, there was a benefit from growing the two species together in terms of LER particularly without fertilizer nitrogen. The higher was N rate the lower was the gain from intercropping for plant biomass yield and N uptake. The relative biomass yield of triticale was almost unaffected by N rate and a reduction in LER was mainly due to decrease in relative biomass yield of field beans. A different pattern of response of triticale to applied nitrogen was observed as N uptake is concerned, because the increasing N rate increased relative N uptake with grain and biomass of the cereal and that resulted in greater LERs for N uptake than those for dry matter yield.

The highest nitrogen rate significantly reduced the nitrogen harvest index and nitrogen use efficiency of triticale irrespective of cropping method (Table 4). Due to interaction between treatments maximum NUE was observed in sole crop triticale at a nitrogen rate of 25 kg/ha, while for intercropped triticale NUE decreased significantly with increased nitrogen input. On the average, NUE of triticale in the intercrop was significantly 6.5% lower than NUE in pure stand. Nitrogen harvest index and NUE of field beans were lower in the intercrop than in pure stand by 9.6 and 12.9%, respectively, however due to interaction of treatments they were equal at a rate of 25 kg N/ha. Irrespective of cropping method NHI and NUE for field beans were unaffected by nitrogen input. Agronomic efficiency of applied nitrogen for triticale was almost three times higher than for field beans and did not differ from intercrop AE. The apparent recovery fraction was not affected by experimental treatments.

DISCUSSION

Results of the experiment show that gain from intercropping of triticale with field beans was greater

Table 4. Nitrogen use efficiency (mean 1999–2000)

N rate (kg/ha)	Cropping method	Triticale		Field beans		N rate (kg/ha)	Cropping method	AE (kg/kg)	RF (%)
		NHI (%)	NUE (kg/kg)	NHI (%)	NUE (kg/kg)				
0	pure stand	81.0	44.5	73.0	16.2	0			
	intercrop	81.1	42.9	63.8	14.1				
	pure stand	80.3	45.6	70.4	16.0	25	triticale	26.6	55.6
25	intercrop	80.9	42.0	70.9	15.3		field beans	9.7	64.6
							intercrop	23.0	52.8
	pure stand	78.9	44.6	75.0	16.8	50	triticale	20.9	47.6
50	intercrop	78.8	41.0	62.6	13.3		field beans	7.9	40.4
							intercrop	17.4	41.6
0		81.1	43.7	68.4	15.2	0			
25		80.6	43.8	70.7	15.7	25		19.8	57.7
50		78.9	42.8	68.8	15.1	50		15.4	43.2
	pure stand	80.1	44.9	72.8	16.4		triticale	23.8	51.6
	intercrop	80.3	42.0	65.8	14.3		field beans	8.8	52.5
							intercrop	20.2	47.2
$HSD_{0.05}$ – nitrogen rate		1.0	0.5	n.s.	n.s.	$HSD_{0.05}$ – nitrogen rate		n.s.	n.s.
$HSD_{0.05}$ – cropping method		n.s.	0.3	3.8	0.9	$HSD_{0.05}$ – cropping method		10.8	n.s.
$HSD_{0.05}$ – interaction		n.s.	0.5	6.5	1.4	$HSD_{0.05}$ – interaction		n.s.	n.s.

for nitrogen uptake than for plant biomass yield. Significantly higher N uptake by intercrop than by both species in pure stand indicates there were partially different sources of nitrogen for components of the intercrop. Complementary use of N in cereal-legume intercrops has been observed also by other authors (Martin and Snaydon 1982, Bulson et al. 1997). Nitrogen fixation by field beans reduced competition from the legume for soil and fertilizer nitrogen causing the nutrient more available for triticale. This probably increased nitrogen content in plants of the cereal. A similar result was also reported for triticale intercropped with common vetch (Sobkowicz and Śniady 2000). On the other hand, relatively high dry matter yield of triticale in the intercrop (RY > 0.5) indicates triticale was a better competitor than field beans for other common resources hampering biomass accumulation by the legume (RY < 0.5). Thus higher grain protein in intercropped legume irrespective of N fertilizer rate, was probably more a result of low nitrogen dilution in grain tissue than enhanced N fixation. Crops acquire nitrogen early in the growing season and next N concentration decreases with plant size during growing period. In intercropped field beans the latter process was probably more restricted by competition from triticale than the first one, because the intensity of competition increases with growth and size of competing species (Sobkowicz 2003).

Intercropping was most profitable at 0 kg N/ha in terms of LER for dry matter yield and N uptake. Lack of fertilizer input in the treatment limited more growth of the cereal than the legume. Hence reduced competition from triticale allowed legume to grow relatively better and to fix more atmospheric N than in the treatments with fertilizer N. The low nitrogen status of light soil could also induce increased N fixation in the legume crop as it was shown by Danso et al. (1987). The addition of fertilizer nitrogen created a negative feedback loop in relation to complementarity phenomenon. Increasing N rate increased the competitive ability of triticale causing a reduction in relative biomass yield of intercropped legume and as a consequence decreasing N fixation per unit area. The results are in agreement with those of Martin and Snaydon (1982) who reported an increase in root competitive ability of barley against field beans after N application. On the other hand, intercropped triticale was unable to utilize the fertilizer nitrogen for grain production to such an extent as in pure stand and this was reflected by reduced NUE with increasing N input. In the unproductive environment of light soil, triticale was unable to yield more grain in the intercrop being only at half of the pure stand plant density with different mechanism accountable probably for depressing NHI and NUE of field beans in the intercrop. The decrease in two indices resulted from increased interference from triticale during grain formation of the legume. Previous results from the experiment showed a reduction in the number of pods per plant and thousand-grain weight of field beans in the intercrop (Sobkowicz and Parylak 2002).

Agronomic efficiency was similar for triticale and intercrop mainly due to strong dominance of the cereal. Low agronomic efficiency of pure stand field beans shows the legume was unable to increase grain yield in response to N applied because there were other resources that limited grain yield of the species. Nevertheless the response of pure stand field beans to applied N did not differ from the response of pure stand triticale in terms of apparent recovery fraction of N. That means field beans were as effective as triticale of fertilizer N acquiring after fertilizer application. Although it was impossible in the experiment to detect which part of the legume nitrogen came from fixation and which from soil and fertilizer pool.

In conclusion, triticale-field beans intercrop is a system efficiently acquiring nitrogen even when other resources are scarce hindering dry matter accumulation by plants. The lower is an external N input the greater is the gain from cereal-legume intercropping due to more effective biological N fixation. Our results suggest that under severe conditions of light soil N fertilizer rate for triticale-field beans intercrop should not exceed 25 kg/ha. That meets the requirements for a more sustainable low-input agriculture.

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ABSTRAKT

Příjem a využití dusíku směskou tritikale (*Triticosecale* Witt.) a bobu (*Vicia faba* var. *minor* L.)

V polních pokusech založených v letech 1999 a 2000 na lehké půdě metodou znáhodněných bloků byl studován vliv různých dávek dusíkatého hnojení (0, 25 a 50 kg N/ha) na výnos sušiny nadzemní biomasy a na příjem a využití N u jarního tritikale a bobu obecného při pěstování v čisté kultuře a ve směsce. Složení směsky odpovídalo polovinám počtu rostlin těchto plodin pěstovaných v čisté kultuře. Ve směsce se zvyšoval u tritikale obsah bílkovin v obilkách a v nadzemní biomase bez ohledu na dodaný N. Zvýšením dávky N z 0 na 25 kg/ha se zvýšil výnos biomasy u tritikale i směsky. Příjem N zrny a biomasou plodin ve směsce byl průkazně vyšší než u čistých kultur, a to i navzdory silné dominanci tritikale nad bobem. Čím vyšší bylo hnojení N, tím menší efekt byl zaznamenán u směsky, a to především v důsledku většího potlačení bobu plodinou tritikale. Agronomická efektivita byla stejná pro tritikale i směsku, byla však průkazně nižší u bobu, což ukazuje na vliv dalších omezujících faktorů pro růst luskoviny.

Klíčová slova: směska; dusíkaté hnojení; tritikale; bob obecný

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