Available online at www.sciencedirect.com
ScienceDirect
Europ. J. Agronomy 25 (2006) 202–207
European Journal of Agronomy
www.elsevier.com/locate/eja

Yield performance and land-use efficiency of barley and faba bean mixed cropping in Ethiopian highlands

Getachew Agegnehu *, Amare Ghizaw, Woldeyesus Sinebo

Holetta Research Centre, Ethiopian Institute of Agricultural Research, Agronomy and Crop Physiology, P.O. Box 2003, Addis Ababa, Ethiopia

Received 6 July 2005; received in revised form 27 April 2006; accepted 17 May 2006

Abstract

Mixed intercropping of barley (*Hordeum vulgare* L.) with faba bean (*Vicia faba* L.) was compared with sole cropping for three growing seasons (2001–2003) at Holetta Agricultural Research Centre, in the central highlands of Ethiopia. The treatments were sole barley (125 kg ha^{-1}), sole faba bean (200 kg ha^{-1}) and an additive series of 12.5, 25, 37.5, 50 and 62.5% of the sole seed rate of faba bean mixed with full barley seed rate. A randomised complete block design replicated four times was used. Mixed cropping and year effects were significant for seed and biomass yields of each crop species. Barley yield was reduced by mixed cropping only when the seed rate of faba bean exceeded 50 kg ha^{-1} or 25% of the sole seed rate. There was no mixed cropping by year interaction effect for barley grain yield but for faba bean seed yield. Total yield, barley yield equivalent, land equivalent ratio (LER) and system productivity index (SPI) of mixtures exceeded those of sole crops especially when faba bean seed rate in the mixture was increased to 75 kg ha^{-1} (37.5%) or more. The highest barley yield equivalent, SPI, crowding coefficient and LER were obtained when faba bean was mixed at a rate of 37.5% with full seed rate of barley. From this study, it is inferred that mixed intercropping of faba bean in normal barley culture at a density not less than 37.5% of the sole faba bean density may give better overall yield and income than sole culture of each crop species.

Keywords: Aggressivity; Barley; Crowding coefficient; Faba bean; Intercropping; Land equivalent ratio; Mixed cropping

1. Introduction

Intercropping of cereals and legumes is important for the development of sustainable food production systems, particularly in cropping systems with limited external inputs (Bulson et al., 1997; Dapaah et al., 2003). In the tropics, cereal/legume intercropping is commonly practised because of yield advantages, greater yield stability and lower risks of crop failure that are often associated with monoculture (Jensen, 1996; Hauggaard-Nielsen et al., 2001; Tsubo et al., 2005). Yield increments resulting from mixed intercropping (Jensen, 1996; Anil et al., 1998; Dapaah et al., 2003; Chen et al., 2004) were attributed mainly to the presence of complimentary effects, better resource use efficiency of the mixed cultures and the buffering effects of the mixtures against diseases and weeds (Willey, 1979; Anil et al., 1998).

One of the advantages of a cereal/legume intercropping in a humid tropical environment is the component crops' ability to utilize different sources of N (Willey, 1979; Benites et al., 1993). The cereal may be more competitive than the legume for soil mineral N, but the legume can fix N symbiotically if effective strains of *Rhizobium* are present in the soil. The complementary use of such growth resources by crops is particularly important in low input subsistence farming systems such as those in East African highlands.

Various measures of the efficiency of intercropping systems relative to sole cropping were employed (Hiebesch and McCollum, 1987). However, the land equivalent ratio (LER) is the most-used convention for intercrop versus sole crop comparisons. Comparisons in competitive ability of the intercrop components were often made by calculating crowding coefficients and aggressivity values as in Willey (1979).

In Ethiopia, crops and cropping systems are diverse owing to large agro-ecological and cultural diversity, which in turn led to variable cropping patterns. Barley (*Hordeum vulgare* L.) and faba bean (*Vicia faba* L.) are major staple food crops among cereals and pulses, respectively, in high altitude areas of Ethiopia.

* Corresponding author. Tel.: +251 1 12370300; fax: +251 1 12370377.
E-mail address: get491663@yahoo.com (G. Agegnehu).

1161-0301/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.eja.2006.05.002

The yearly average main season area covered by barley is about 0.92 million ha making up 13% of the total cereal area. The area sown to faba bean averages 0.38 million ha making up 36% of the area allotted to pulses (CSA, 2004). In northern Ethiopia and Eritrea, barley is commonly mixed cropped with wheat (Araia, 2001). Such intercrops are largely heterogeneous mixtures of landraces of the component crops. However, the continuous distribution of modern varieties has changed the landscape of on-farm crop genetic diversity, increasingly leading to the growing of genetically uniform varieties. Even then, because of the growing population pressure and the need to produce diverse products from the ever-shrinking land holdings, farmers in northern Ethiopia have recently started mixed cropping of pulses such as faba bean with improved varieties of cereals, notably wheat and tef (*Eragrostis tef* Zucc.). However, in the central highlands of Ethiopia, farmers rarely practice cool-season cereal/pulse intercropping. In view of the numerous perceived advantages of cereal/pulse intercropping, this may constitute a lost opportunity in a farming system where population growth and land shortage associated therewith are increasingly looming large. The goal of the present study was to assess the agronomic feasibility of introducing barley/faba bean mixed cropping as a means of sustainable intensification of crop production in the farming systems of the central highlands of Ethiopia. The specific objectives were to compare the productivity of barley/faba bean mixed cropping compared to sole cultures, and to examine the competitive relationships of barley and faba bean in intercrops.

2. Materials and methods

2.1. Study area

The experiment was conducted for three years (2001–2003) on a Eutric Nitisol (FAO classification) of Holetta Agricultural Research Centre (latitude 09°03′N, longitude 38°30′E and altitude of 2390 m above sea level) in the Central Highlands of Ethiopia. The rainfall is bimodal with long-term average annual rainfall of 1055 mm, about 85% of which is received from June to September and the rest from January to May. Long-term average minimum and maximum air temperatures are 6 and 22 °C, respectively. Experimental fields were ploughed using tractor drawn implements. Soil physical and chemical properties of the experimental fields were determined for samples taken during planting in the Soil and Plant Analysis Laboratory of Holetta Agricultural Research Center (Table 1).

Table 1
Physico-chemical properties of soil (0–20 cm) at the experimental site

Parameter	Value	Parameter	Value
Clay (%)	56.06	NO_3-N (ppm)	7.87
Silt (%)	28.58	Available P (ppm)[a]	7.53
Sand (%)	15.36	Available Na (meq/100 g)	0.10
pH (1:1 H_2O)	4.92	Available K (meq/100 g)	1.28
OC (%)	1.65	Available Ca (meq/100 g)	2.74
Total N (%)	0.15	Available Mg (meq/100 g)	2.09

[a] Bray II method.

2.2. Treatments, design and data collection

The treatments were mixed cropping by broadcasting of faba bean in barley at seed rates of 12.5, 25, 37.5, 50 or 62.5% of the sole faba bean seed rate (200 kg ha^{-1}) plus sole cultures of the two crops. Barley was seeded at the recommended rate of 125 kg ha^{-1} in both sole and mixed cultures. The varieties used were HB-42 for barley and CS20DK for faba bean. The design was randomised complete block with four replications. A plot size of 5 m × 5 m was used. Pulses were the preceding crops in 2001 and 2002 and tef (*Eragrostis tef* Zucc.) in 2003. Experimental plots of pure barley and mixed crops received the recommended rate of 41/20 kg NP ha^{-1} and pure faba bean plots received 18/20 kg NP ha^{-1} all applied at planting. The experiment was planted on June 21 in 2001, June 22 in 2002 and June 24 in 2003, and harvested on November 20 in 2001, November 14 in 2002 and November 7 in 2003.

Crops of the mixed cultures were harvested separately from the whole plot. Grain or seed yield, some yield components, above ground biomass, plant height, nodule number, disease and weed biomass were recorded. Nodulation score was recorded on a 0–4 scale, where 0 indicates no nodule per plant and 4 more than 30 nodules per plant. Chocolate spot disease (*Botrytis fabae* Sard.) of faba bean was recorded on a 1–9 scale, where 1 indicates no disease symptoms or very small specks on leaves and 9 extensive lesions on leaves, stems and flowers.

Seeds were weighed and adjusted to constant moisture levels of 12 and 10% for barley and faba bean, respectively. Barley was considered as the main crop and faba bean as an intercrop component. Then grain yield of faba bean from each plot was converted to barley equivalent yield of mixed cropping system as follows:

$$\mathrm{EY_{fb}} = Y_{\mathrm{fb}} \times \frac{P_1}{P_2}$$

$$\mathrm{EY}_i = Y_{\mathrm{b}} + \mathrm{EY_{fb}}$$

where $\mathrm{EY_{fb}}$ is barley equivalent yield of faba bean (kg ha^{-1}), Y_{fb} the yield of faba bean (kg ha^{-1}), P_1 the price of faba bean (US$ 0.18 kg^{-1}), P_2 the price of barley (US$ 0.15 kg^{-1}), EY_i barley equivalent yield of mixed cropping system (kg ha^{-1}) and Y_{b} is barley grain yield (kg ha^{-1}).

The relative advantage of mixed cropping compared to sole culture was calculated for each proportion using total land equivalent ratio (LER) as:

$$\mathrm{LER} = \frac{Y_{ij}}{Y_{ii}} + \frac{Y_{ji}}{Y_{jj}}$$

where Y_{ii} and Y_{jj} denote yields of crops i and j in sole culture and Y_{ij} and Y_{ji} are the corresponding yields in mixed crops.

The competitive relationships between the two crops were determined using the crowding coefficient (k) and aggressivity (A) values suggested by Willey (1979) as:

$$\text{Crowding coefficient of barley } (K_{\mathrm{ab}}) = \frac{Y_{\mathrm{ab}} \times Z_{\mathrm{ba}}}{(Y_{\mathrm{aa}} - Y_{\mathrm{ab}}) \times Z_{\mathrm{ab}}}$$

Table 2
Monthly total rainfall, monthly mean maximum and minimum temperatures during the growth seasons and the 30-year average

Year	April	May	June	July	August	September	October	November	Total
Monthly total rainfall (mm)									
2001	49	101	176	302	162	103	24	0	917
2002	37	49	123	273	194	77	0	0	753
2003	84	14	117	194	237	107	10	0	763
30-year mean	78	68	115	247	260	128	23	9	928
Monthly mean maximum temperature (°C)									
2001	23.8	23.5	21.7	20.2	18.9	20.1	21.5	22.7	21.6
2002	25.3	25.6	22.9	20.9	20.3	21.2	23.3	23.9	22.9
2003	23.3	23.3	21.5	18.1	18.7	19.7	21.9	22.4	21.1
30-year mean	23.7	23.9	22.2	19.5	19.2	20.2	21.7	22.3	21.6
Monthly mean minimum temperature (°C)									
2001	6.4	5.5	6.7	7.9	8.2	5.1	3.5	1.1	5.6
2002	8.3	8.9	7.8	9.1	8.3	6.8	4.6	2.1	7.0
2003	9.4	8.3	7.9	9.2	9.1	7.8	3.8	2.2	7.2
30-year mean	8.1	7.7	7.4	8.9	9.0	7.6	4.6	2.1	6.9

$$\text{Crowding coefficient of faba bean } (K_{ba}) = \frac{Y_{ba} \times Z_{ab}}{(Y_{bb} - Y_{ba}) \times Z_{ba}}$$

$$\text{Aggresivity of barley } (A_{ab}) = \frac{Y_{ab}}{Y_{aa} \times Z_{ab}} - \frac{Y_{ba}}{Y_{bb} \times Z_{ba}}$$

$$\text{Aggressivity of faba bean } (A_{ba}) = \frac{Y_{ba}}{Y_{bb} \times Z_{ba}} - \frac{Y_{ab}}{Y_{aa} \times Z_{ab}}$$

where Y_{aa} is the pure culture yield of barley, Y_{bb} the pure culture yield of faba bean, Y_{ab} the mixed culture yield of barley, Y_{ba} the mixed culture yield of faba bean, Z_{ab} the sown proportion of barley and Z_{ba} is the sown proportion of faba bean. Another index for assessing intercrops is the system productivity index (SPI), presented by Odo (1991), which standardizes the yield of the secondary crop, b, in terms of the primary crop, a.

$$\text{SPI} = \frac{S_a}{S_b} Y_b + Y_a$$

where S_a and S_b are the mean yield of barley and faba bean in sole culture and Y_a and Y_b are the mean yield of barley and faba bean in mixed culture.

2.3. Statistical analysis

Analysis of variance was performed using the SAS statistical package program Version 8.2 (SAS Institute, 2001). The total variability for each trait was quantified using pooled analysis of variance over years as per the following model:

$$P_{ijk} = \mu + Y_i + R_{j(i)} + T_k + \text{TY}_{(ik)} + e_{ijk}$$

where P_{ijk} is total observation, μ the grand mean, Y_i the effect of the ith year, $R_{j(i)}$ the effect of the jth replication within the ith year, T_k the effect of the kth treatment, $\text{TY}_{(ik)}$ the interaction of kth treatment with ith year and e_{ijk} is the random error.

3. Results

3.1. Weather

Total precipitation during the growing season (June–October) was greater by about 100 mm in 2001 than either 2002 or 2003 (Table 2). Rainfall in September was more than 80% of the long-term average in 2001 and 2003 and only about 60% of the long-term average in the year 2002. There was 24 mm of rain in 2001 and 10 mm in 2003 and no rain in 2002 for the month of October. In fact, the last shower of rain was received on 22 September in the year 2002 exposing the crops to moisture stress during the grain-filling months of September and October. Night temperatures were cooler during the entire crop growing season in 2001. This together with high and more evenly distributed rainfall in 2001 means longer crop growth duration and larger biomass accumulation leading to higher grain yield in this year. Hence the year 2001 was much better than either year 2002 or 2003 for crop growth and development as also reflected on the yields of both crops.

3.2. Growth and yields of component crops

The year effect was significant ($P = 0.01$) for grain and biomass yields of both crops (Tables 3–5). Mean grain yields of each of the two species were higher in the year 2001 than in either 2002 or 2003. There were highly significant ($P = 0.001$) differences among treatments for biomass and grain yields of each crop species (Table 3). Sole yields of each crop were greater than the respective yields in mixtures. Increasing faba bean proportion from 12.5 to 62.5% increased faba bean seed yields from 12 to 48% but lowered barley grain yields from 93 to 73% of the respective sole crop yields. Total grain yield and barley yield equivalents also increased as the seeding percentage of faba bean in the mixture increased. The highest total mixed crop yield was

Table 3
Effects of mixed cropping of barley and faba bean on grain yields of component crops, barley yield equivalent, and partial and total land equivalent ratios (LERs) at Holetta, Ethiopia

Treatments	Grain yield (kg ha^{-1})		Total grain yield (kg ha^{-1})	Barley yield equivalent (kg ha^{-1})	Partial and total LER values		
	Barley	FB[a]			Barley	FB	Total
Year							
2001	2744a[b]	1470a	4214	3790a	0.88a	0.39c	1.07b
2002	1488c	665b	2153	1979c	0.81b	0.55a	1.17a
2003	1896b	1320a	3216	3050b	0.85a	0.46b	1.16a
LSD (0.05)	213.91	201.66		200.68	0.04	0.06	0.06
Mix-proportion (%)							
Sole barley	2396a	–	2396	2396d	1.00a	–	1.00c
Sole faba bean	–	2521a	2521	3181a	–	1.00a	1.00c
Barley/FB (100:12.5)	2237ab	312e	2549	2630cd	0.93b	0.12e	1.05bc
Barley/FB (100:25)	2036bc	576d	2612	2762bc	0.85c	0.23d	1.08b
Barley/FB (100:37.5)	2042bc	945c	2987	3233a	0.85c	0.38c	1.23a
Barley/FB (100:50)	1831cd	1023c	2854	3120ab	0.76d	0.41c	1.17a
Barley/FB (100:62.5)	1762d	1203b	2965	3278a	0.73d	0.48b	1.21a
LSD (0.05)	271.1	178.4		306.5	0.12	0.07	0.13
Year × treatment	NS	***		NS	NS	*	NS
CV (%)	16.1	20.0		12.8	16.7	17.2	13.9

*, ***Significant at 0.05 and 0.001 probability levels, respectively; ns, not significant.
[a] FB, faba bean.
[b] Means in a column with the same letters are not significantly different at $P = 0.05$.

obtained when faba bean at a rate of 37.5% was mixed with full barley (Table 3).

Increasing the proportion of faba bean in the mixture from 12.5 to 62.5% of the sole seed rate decreased barley straw yield (difference of biomass and grain yields in Tables 3 and 4) from 89 to 70% and increased faba bean straw yield from 11 to 42% of the respective sole crop straw yields. Weed biomass and chocolate spot disease were significantly lower in mixed culture compared to sole culture (Tables 4 and 5). The year by mixed intercropping interaction effect was highly significant ($P = 0.01$) for grain and biomass yields of faba bean but not for barley (Tables 3–5).

3.3. Land-use efficiency and competitive ability

Differences among years and treatments were highly significant ($P = 0.01$) for LERs. Grain yields were lower but total LER were higher for the years 2002 and 2003 than for the year 2001 (Table 3). Partial LERs were higher for faba bean and lower for barley in the year 2002 than any of the other two years. Partial LERs decreased from 0.93 to 0.73 for barley and increased from 0.12 to 0.48 for faba bean when the faba bean density in the mixture increased from 12.5 to 62.5% of the sole faba bean seed rate. The highest total LER of 1.23 was obtained from the

Table 4
Treatment effects summary for major agronomic characters of barley grown in mixed and sole culture at Holetta, Ethiopia

Factor	BY[a] (kg ha^{-1})	TKW (g)	PHT (cm)	TIL (m^{-2})	WDM (g m^{-2})	SC (m^{-2})
Year						
2001	8650a[b]	50	120	341	49b	184b
2002	4448b	48	114	307	67a	160c
2003	5233b	46	117	324	34c	212a
LSD (0.05)	808.83	NS	NS	NS	7.41	15.01
Mix-proportion (%)						
Sole barley	6816a	49	119	394a	61a	192
Barley/FB (100:12.5)	6142ab	49	113	341ab	47b	184
Barley/FB (100:25)	6008ab	49	117	283b	46b	191
Barley/FB (100:37.5)	6000ab	47	118	335ab	41bc	184
Barley/FB (100:50)	5768b	47	117	309b	43bc	180
Barley/FB (100:62.5)	5711b	48	117	281b	37c	180
LSD (0.05)	1017.6	NS	NS	75.5	11.3	NS
Year × treatment	NS	NS	NS	NS	**	NS
CV (%)	20.4	5.1	7.5	28.4	27.6	14.0

**Significant at 0.01 probability level; NS, not significant.
[a] BY, biomass yield; TKW, thousand kernel weight; PHT, plant height; TIL, number of tillers; WDM, weed dry matter; SC, stand count.
[b] Means in a column with the same letters are not significantly different at $P = 0.05$.

Table 5
Treatment effects summary for major agronomic traits of faba bean grown in mixed and sole culture at Holetta, Ethiopia

Factor	BY[a] (kg ha^{-1})	TSW (g)	PPP (No.)	PHT (cm)	NDN (0–4 scale)	CHSPT (1–9 scale)	SC (m^{-2})
Year							
2001	3001a[b]	589a	12.1a	143a	2.2c	3.2b	18b
2002	1666b	570b	7.2b	111c	3.4a	3.8a	17b
2003	2684a	509c	10.5a	119b	2.8b	3.4ab	22a
LSD (0.05)	376.7	14.3	1.6	5.0	0.3	0.4	2.0
Mix-proportion (%)							
Sole faba bean	5600a	539c	10.5	131a	2.9	4.2a	34a
Barley/FB (100:12.5)	653e	576a	9.4	116c	2.7	3.4bc	9e
Barley/FB (100:25)	1282d	559ab	10.2	122bc	3.2	2.8c	13d
Barley/FB (100:37.5)	1776c	548bc	10.6	126ab	2.6	3.2bc	16c
Barley/FB (100:50)	2058c	562ab	9.6	124ab	2.6	3.0c	19c
Barley/FB (100:62.5)	2494b	553bc	9.0	127ab	2.7	3.6b	22b
LSD (0.05)	391	20.2	NS	7.1	NS	0.5	2.9
Year × treatment	**	**	NS	**	**	**	**
CV (%)	20.6	4.4	28.6	7.0	20.8	18.6	18.6

*,**Significant at 0.01 probability level, respectively; NS, not significant.
[a] BY, biomass yield; TSW, thousand seed weight; PPP, pods per plant; PHT, plant height; NDN, nodule number; CHSPT, chocolate spot; SC, stand count.
[b] Means in a column with the same letters are not significantly different at $P = 0.05$.

Table 6
Relative crowding coefficient (k), product of the coefficients (K), aggressivity (A) and system productivity index (SPI) of barley and faba bean grown in mixed culture at Holetta, Ethiopia

Treatments	k value			A value		
Mix-proportion (%)	Barley	Faba bean	K	Barley	Faba bean	SPI
Barley/FB (100:12.5)	1.76	1.13	1.99	−0.60	0.60	2534
Barley/FB (100:25)	1.41	1.18	1.66	−0.20	0.20	2583
Barley/FB (100:37.5)	2.16	1.53	3.30	−0.40	0.40	2940
Barley/FB (100:50)	1.62	1.36	2.20	−0.50	0.50	2803
Barley/FB (100:62.5)	1.74	1.46	2.54	−0.20	0.20	2905
Mean	1.74	1.33	2.34	−0.30	0.30	2753

binary combination of 100:37.5 barley:faba bean (Table 3). Total LERs showed a positive relationship with the total grain yields of the two component crops (Table 3). The year by treatment interaction effect was significant only for partial LERs of faba bean.

The crowding coefficients (k) for both barley and faba bean were the most at 100:37.5 barley:faba bean, in which total yield, LER and SPI were also the highest. The aggressivity (A) parameter also indicated a tendency for faba bean to dominate barley in mixtures (Table 6).

4. Discussion

Although seed yields of the component crops in mixtures were low as compared to their respective sole crop yields, the total land productivity was improved in mixed cultures as supported by higher total LERs. Mean values of LER ranging from 1.05 to 1.23 were obtained from different mixed proportions of barley and faba bean. This means the sole culture of each crop requires 5 to 23% more land than the mixed crop to produce equal yields indicating greater land-use efficiency of intercrops than sole crops. Similar results were reported for mixed cultures of lentil and barley (Kallu and Erhabor, 1990), pea and barley (Jensen, 1996; Chen et al., 2004), field bean and wheat (Bulson et al., 1997; Haymes and Lee, 1999; Hauggaard-Nielsen et al., 2001) and maize and faba bean (Li et al., 1999).

Years 2002 and 2003 in general and year 2002 in particular were years of high moisture stress during the critical grain-filling months of September and/or October. Nonetheless, the average efficiency of mixed cropping as measured by total LERs was significantly higher in 2002 and 2003 than in 2001. This might indicate a more efficient utilization of growth resources and thereby greater yield stability under stress by a mixed cropping than a sole cropping system. Similarly, Tesfamichael and Reddy (1996) reported greater intercrop yield advantage from a low rainfall area (high stress environment) than a medium rainfall area (low stress environment). Rao and Willey (1980) also found a much less probability of crop failure in pigeon pea/sorghum intercrop than sole crop of either pigeonpea or sorghum.

Severity of chocolate spot disease appeared more serious on sole culture of faba bean than mixed culture, probably because the microclimate created by the denser faba bean canopy in sole

culture favoured disease development. In this study, reduction in weed biomass in the mixture than in sole barley agrees with the findings of Carr et al. (1995) for wheat/lentil intercrop, Bulson et al. (1997) for wheat/field bean intercrop and Holland and Brummer (1999) for berseem clover/oat intercrop combinations. Weeds are notable agronomic problems on barley in the central highlands of Ethiopia and hand weeding is often used to control barley weeds in the region. Thus, the increased suppression of weeds in the mixture may ease pressure on labour for manual weed control and thereby enhance the likelihood of adoption of barley/faba bean mixed cropping.

In this study, barley grain yield decreased with increase in faba bean density and yield. More barley yield reduction is expected with the increase in faba bean density beyond used in this study implying domination of barley by faba bean. Even with the faba bean densities used in this study, the relatively lower k and negative A values for barley indicate the suppression of barley by faba bean. Willey (1979) reported that a crop with relatively lower k and negative A values is normally regarded as being dominated while the one with the opposite value is dominant.

5. Conclusion

In Ethiopia, sustainable maximization of economic yields of crops such as barley and faba bean is among the cardinal goals of research and extension systems. Mixed intercropping of barley and faba bean could be economically and environmentally promising in the Ethiopian highlands, a region characterized by high population density, small farm size and low farm income. In this study, despite the reduction of barley yield due to the addition of faba bean companion crop to barley, the mixed culture as a whole exhibited higher total productivity as measured by total grain yield and total LERs of the two crops. The complimentary use of nutrient and water sources by the intercrop components and the need for less external inputs resulting from cereal/pulse mixed cropping are auspicious, calling for further attention from research and development stakeholders in the Ethiopian highlands.

One of the prime objectives of contemporary intercropping studies is to assess the N economy of the component crops. However, the present study is deficient in this aspect and, therefore, future studies should assess the extent of N capture accruing from intercropping. In addition, it may be important to evaluate up to 100% addition of faba bean in full seed rate culture of barley. In the meantime, from this study, we suggest that mixed intercropping of faba bean in normal barley culture at a density not less than 37.5% of the sole faba bean may give better overall yield and income than sole culture of each crop species.

Acknowledgements

The Highland Food Legumes Project, sponsored by the Royal Netherlands Government and the Ethiopian Institute of Agricultural Research, is highly acknowledged for funding this experiment. We thank Mr. Beyene Ofa and Mr. Ayalew Adella for their assistance in the execution of the field experiment.

References

Anil, L., Park, J., Phipps, R.H., Miller, F.A., 1998. Temperate intercropping of cereals for forage: a review of the potential for growth and utilization with particular reference to the UK. Grass Forage Sci. 53, 301–317.

Araia, W., 2001. Mixed cropping of barley (*Hordeum vulgare*) and wheat (*Triticum aestivum*) landraces in the central highlands of Eritrea. Ph.D. Thesis. Wageningen University, the Netherlands.

Benites, J.R., McCollum, R.E., Naderman, G.C., 1993. Production efficiency of intercrops relative to sequentially planted sole crops in a humid tropical environment. Field Crops Res. 31, 1–18.

Bulson, H.A.J., Snaydon, R.W., Stopes, C.E., 1997. Effects of plant density on intercropped wheat and field beans in an organic farming system. J. Agric. Sci. 128, 59–71.

Carr, M.P., Gardner, C.J., Schatz, G.B., Zwinger, W.S., Guldan, J.S., 1995. Grain yield and weed biomass of a wheat-lentil intercrop. Agron. J. 87, 574–579.

Central Statistics Authority (CSA), 2004. Agricultural Sample Survey: Report on Area under Cultivation Yield and Production of the Major Crops. CSA, Addis Ababa, Ethiopia.

Chen, C., Westcott, M., Neill, K., Wichmann, D., Knox, M., 2004. Row configuration and nitrogen application for barley-pea intercropping in Montana. Agron. J. 96, 1730–1738.

Dapaah, H.K., Asafu-Agyei, J.N., Ennin, S.A., Yamoah, C.Y., 2003. Yield stability of cassava, maize, soybean and cowpea intercrops. J. Agric. Sci. 140, 73–82.

Hauggard-Nielson, H., Ambus, P., Jensen, E.S., 2001. Evaluating pea and barley cultivars for complementarity in intercropping at different levels of soil N availability. Field Crops Res. 72, 185–196.

Haymes, R., Lee, H.C., 1999. Competition between autumn and spring planted grain intercrops of wheat (*Triticum aestivum*) and field bean (*Vicia faba*). Field Crops Res. 62, 167–176.

Hiebesch, C.K., McCollum, R.E., 1987. Area × time equivalency ratio: a method for evaluating the productivity of intercrops. Agron. J. 79, 15–22.

Holland, J.B., Brummer, E.C., 1999. Cultivar effects on oat–berseem clover intercrops. Agron. J. 91, 321–329.

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

Kallu, B.A., Erhabor, P.O., 1990. Barley, lentil and flax yield under different intercropping systems. Agron. J. 82, 1066–1068.

Li, L., Yang, S., Li, X., Zhang, F., Christie, F., 1999. Interspecific complementary and competitive interactions between intercropped maize and faba bean. Plant Soil 212, 105–114.

Odo, P.E., 1991. Evaluation of short and tall sorghum varieties in mixtures with cowpea in the Sudan savanna of Nigeria: land equivalent ratio, grain yield and system productivity index. Expl. Agric. 27, 435–441.

Rao, M.R., Willey, R.W., 1980. Evaluation of yield stability in intercropping: studies on sorghum/pigeonpea. Expl. Agric. 16, 105–116.

SAS Institute, 2001. SAS/STAT User's Guide, Version 8.2. SAS Institute, Cary, NC.

Tesfamichael, N., Reddy, M.S., 1996. Maize/bean intercropping effects on component yield, land use efficiency and net-returns at Awassa and Melkassa. In: Sinebo, W., Tadele, Z., Alemayehu, N. (Eds.), Proceedings of the 1st Conference of the Agronomy and Crop Physiology Society of Ethiopia. Addis Ababa, Ethiopia, pp. 51–55.

Tsubo, M., Walker, S., Ogindo, H.O., 2005. A simulation model of cereal-legume intercropping systems for semi-arid regions II. Model application. Field Crops Res. 93, 23–33.

Willey, R.S., 1979. Intercropping—its importance and research needs. Part 1. Competition and yield advantages. Field Crop Abstr. 32, 1–10.