Expl Agric. (2006), volume 42, pp. 495–504 © *2006 Cambridge University Press*
doi:10.1017/S0014479706003863 *Printed in the United Kingdom*

CROP PRODUCTIVITY AND LAND-USE EFFICIENCY OF A TEFF/FABA BEAN MIXED CROPPING SYSTEM IN A TROPICAL HIGHLAND ENVIRONMENT

By GETACHEW AGEGNEHU†, AMARE GHIZAW
and WOLDEYESUS SINEBO

Holetta Research Centre, Ethiopian Agricultural Research Organisation, P.O. Box 2003, Addis Ababa, Ethiopia

(*Accepted 27 April 2006*)

SUMMARY

Mixed cropping of teff (*Eragrostis tef*) with faba bean (*Vicia faba*) was compared with sole cropping in the 2002 and 2003 growing seasons at Holetta Research Centre, in the central highlands of Ethiopia. The treatments were sole teff (25 kg seed ha^{-1}), sole faba bean (200 kg seed ha^{-1}) and 12.5, 25, 37.5, 50 and 62.5 % of the sole seed rate of faba bean mixed with a full teff seed rate. A randomized complete block design replicated four times was used. Treatment effects were significant for seed and biomass yields of each crop species. Increasing the seed rate of faba bean in teff/faba bean mixture increased faba bean seed yield but decreased teff grain yield. Nonetheless, mixed cropping of faba bean with teff increased land use efficiency and gave higher total yields compared to growing either species in sole culture. Teff yield equivalent, land equivalent ratios (LERs) and system productivity index (SPI) of the mixtures exceeded those of sole crops especially when the seed rate of faba bean in the mixture was increased to 50 kg ha^{-1} (25 %) or more. The relatively high crowding coefficient values indicated yield advantages from mixed cropping of the two species. The highest values of teff yield equivalent, LER and SPI were obtained when faba bean was mixed at a rate of 62.5 % with the full seed rate of teff. We suggest that, at the current prices of the respective crops, up to 62.5 % of faba bean can be mixed in normal teff to get better total yield and income than sole culture of either species.

INTRODUCTION

Intercropping of annual cereal and grain legumes is a common practice in the tropics because total grain yield is enhanced compared to sole cropping. In addition, intercropping provides a balanced diet, minimizes risks of crop failure due to adverse effects of pests, improves the use of limited resources, reduces soil erosion, increases yield stability and provides higher returns (Anil *et al.*, 1998; Dapaah *et al.*, 2003; Jensen, 1996; Willey, 1979).

Intercropping of cereals and legumes often gives higher resource use efficiency compared to sole cropping (Ofori and Stern, 1987) because intercropping of species that differ in the time of their maximum demands on the environmental resources extends the duration of resource use (Willey, 1979). Furthermore, intercropping of a legume with a non-legume would be valuable because the component crops can utilize different sources of N (Benites *et al.*, 1993; Chu *et al.*, 2004; Jensen, 1996; Willey,

† Corresponding author: get491663@yahoo.com

1979). 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. Such complementarity of crops in resource use is particularly important in low input subsistence farming systems such as those in the East African highlands. Various measures of the efficiency of intercropping systems relative to sole cropping have been employed (e.g. Hiebsch and McCollum, 1987). The land equivalent ratio (LER) is the most used convention for intercrop v. sole crop comparisons, and LER is often higher for intercrops than for sole crop cultures.

Crops and cropping systems in Ethiopia are diverse owing to large agro-ecological and cultural diversity, which in turn has led to variable cropping patterns. Teff (*Eragrostis tef*) and faba bean (*Vicia faba*) are the most important staple food crops among cereals and pulses respectively in Ethiopia. The yearly average main season area covered by teff is about 1.91 million ha making up 29 % 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 Ethiopia, major intercrop combinations traditionally involve cereals with cereals, cereals with legumes and perennials such as trees with annual crops (Georgis *et al.*, 1990). Such intercrops particularly in the cooler northern highlands of Ethiopia are largely heterogeneous mixtures of landraces of the component crops. However, the continuous diffusion of modern varieties has changed the landscape of on-farm crop genetic diversity increasingly leading to the growing of genetically uniform varieties. 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, particularly faba bean, in addition to the main cereal crops, notably wheat and teff. Despite the urgent need for intensification of crop production, in the central highlands of Ethiopia where teff and wheat are grown with relatively high external inputs such as commercial fertilizers and broad leaf herbicides, farmers rarely practice cereal/pulse intercropping. This may constitute a lost opportunity in a farming system where population growth and the associated land shortages are looming increasingly large. The aim of the present study was to assess the agronomic feasibility of introducing teff/faba bean mixed cropping as a means of sustainable intensification of the farming systems in the central highlands of Ethiopia. The specific objectives were to compare the productivity of teff/faba bean mixed cropping compared to sole cultures and to examine the competitive interactions of teff and faba bean in intercrops.

MATERIALS AND METHODS

The experiment was conducted in the 2002 and 2003 main cropping seasons at Holetta Agricultural Research Centre (latitude 09°03′N, longitude 38°30′E, altitude 2390 m asl) in the Central Highlands of Ethiopia. The rainfall is bimodal with a long-term average annual total of 1055 mm. The average minimum and maximum air temperatures are 6 and 22 °C respectively. The soil is a Eutric Nitisol (FAO classification). Soil physical and chemical properties of the trial fields determined during planting are given in Table 1.

Table 1. Physical and chemical properties of fine clay loam soil from the upper surface.

Property	Value	Qualifier
Physical		
Soil texture (%)		
Sand	15.4	
Silt	28.6	
Clay	56.1	
Chemical		
pH (1:1 H_2O)	4.92	Acidic
Organic carbon (%)	1.65	Medium
Total N (%)	0.15	Medium
Available P (ppm)†	7.53	Low
Available Na (meq 100 g^{-1})	0.10	Low
Available K (meq 100 g^{-1})	1.28	Low
Available Ca (meq 100 g^{-1})	2.74	Low
Available Mg (meq 100 g^{-1})	2.09	Low
CEC (meq 100 g^{-1})	22.00	Medium

† Bray-II method.

The treatments were mixed cropping of faba bean in teff 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. Teff was seeded at the recommended rate of 25 kg ha^{-1} in both sole and mixed cultures. The varieties used were DZ-01-354 for teff and CS20DK for faba bean. The design was a randomized complete block with four replications. A plot size of 5 m × 5 m was used. Pulses were the preceding crops in both seasons. Experimental plots of pure teff and mixed crops received the recommended rate of 40:26 kg NP ha^{-1} and pure faba bean plots received 18:20 kg NP ha^{-1} at planting. All other cultural practices were maintained invariably as per the recommendations.

Crops of the mixed cultures were harvested separately from the whole plot. Grain or seed yield, yield components, above ground biomass, plant height, crop lodging and weed biomass were recorded. Seeds were weighed and adjusted to constant moisture levels of 12 % and 10 % for teff and faba bean respectively. A lodging score for teff (0–5 scale) was recorded according to Caldicott and Nuttall (1979) in which 0 indicates that all plants in a plot were upright and 5 indicates all plants were flat on the plot.

Teff was considered as the main crop and faba bean as the companion and thus the grain yield of faba bean from each plot was converted into an equivalent yield of teff in the mixed cropping system as follows:

$$EY_{fb} = \frac{Y_{fb} \times P_1}{P_2} \quad (1)$$

$$EY_i = Y_t + EY_{fb} \quad (2)$$

where EY_{fb} is the teff equivalent yield of faba bean (kg ha^{-1}), Y_{fb} is the yield of faba bean (kg ha^{-1}), P_1 is the average of two seasons price of faba bean (ETB 1.60 kg^{-1}),

P_2 is the average of two seasons price of teff (ETB 2.34 kg^{-1}), EY_i is the teff equivalent yield of the mixed cropping system (kg ha^{-1}) and Y_t is teff grain yield (kg ha^{-1}).

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

$$LER = \frac{Y_{ij}}{Y_{ii}} + \frac{Y_{ji}}{Y_{jj}} \tag{3}$$

where Y_{ii} and Y_{jj} denote yields of crops i and j in sole culture and Y_{ij} and Y_{ji} the corresponding yields in mixed crops. When LER measures 1.0, it indicates that the mixed cropping and sole cropping have yield equivalence, LERs above 1.0 show mixed cropping has a yield advantage over sole cropping, while values below 1.0 show a disadvantage of mixed cropping. Analysis of variance was performed on agronomic traits, LER and teff yield equivalent using the SAS statistical package program version 8.2 (SAS Institute, 2001).

The competitive relationship between the two crops, the crowding coefficient (k) and aggressivity (A) were determined based on Willey (1979) using mean grain yield values of treatments averaged across years and replications as:

$$\textit{Crowding coefficient of teff}\ (k_{ab}) = \frac{Y_{ab} \times Z_{ba}}{(Y_{aa} - Y_{ab}) \times Z_{ab}} \tag{4}$$

$$\textit{Crowding coefficient of faba bean}\ (k_{ba}) = \frac{Y_{ba} \times Z_{ab}}{(Y_{bb} - Y_{ba}) \times Z_{ba}} \tag{5}$$

$$\textit{Aggressivity of teff}\ (A_{ab}) = \frac{Y_{ab}}{Y_{aa} \times Z_{ab}} - \frac{Y_{ba}}{Y_{bb} \times Z_{ba}} \tag{6}$$

$$\textit{Aggressivity of faba bean}\ (A_{ba}) = \frac{Y_{ba}}{Y_{bb} \times Z_{ba}} - \frac{Y_{ab}}{Y_{aa} \times Z_{ab}} \tag{7}$$

where Y_{aa} and Y_{bb} = sole culture yield of teff and faba bean averaged across years and replications, Y_{ab} and Y_{ba} = mixed culture yield of teff and faba bean averaged across years and replications, and Z_{ab} and Z_{ba} = sown proportion of teff and faba bean respectively.

The system productivity index (SPI) was calculated based on Odo (1991):

$$SPI = \frac{S_a}{S_b} Y_b + Y_a \tag{8}$$

where S_a and S_b = mean yield of teff and faba bean in sole culture, and Y_a and Y_b = mean yield of teff and faba bean in mixed culture.

RESULTS

Weather

Rainfall during the planting month of June was close to the long-term average in both years (Table 2). As usual, rainfall totals in July and August were the highest,

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

Monthly total rainfall (mm)									
Year	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Total
2002	37	49	123	273	194	77	0	0	753
2003	84	14	117	194	237	107	10	0	763
30-yr mean	78	68	115	247	260	128	23	9	928
Monthly mean maximum temperature (°C)									
Year	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Mean
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-yr mean	23.7	23.9	22.2	19.5	19.2	20.2	21.7	22.3	21.6
Monthly mean minimum temperature (°C)									
Year	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Mean
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-yr mean	8.1	7.7	7.4	8.9	9.0	7.6	4.6	2.1	6.9

exceeding 194 mm for each month in both years. Nonetheless, rainfall was only 60 % of the long-term average for September 2002. In fact, the last shower of rain fell on 22 September in that year exposing the crops to moisture stress during the grain filling months of September and October. There were three rainy days in the last week of September followed by a 10 mm rain shower on October 10 in 2003. In 2002, the night temperature was about 1 °C lower than in 2003, in the months of August and September further delaying crop development and exposing the crop to late season moisture stress in 2002. Hence, 2003 was better than 2002 for crop growth and development as reflected in the yields of the cereal component of the intercrop.

Crop growth and yield

There were very significant ($p \leq 0.001$) differences among treatments for grain yields of teff and faba bean (Table 3). Sole yields of each crop were greater than the respective yields in mixtures. Increasing the faba bean proportion from 12.5 to 62.5 % increased faba bean seed yields from 21 to 72 % but decreased teff grain yields from 92 % to 60 % of the respective sole crop yields. Mixed cropping of faba bean in teff resulted in higher total grain yield and teff yield equivalents compared to the sole crops. On the basis of seeding percentages in the mixtures, all the mixed proportions resulted in more relative yields of faba bean than expected (Table 3). However, the straw portion of the total biomass harvested was less than that of sole teff alone. As the proportion of faba bean in the mixture increased from 12.5 % to 62.5 %, the straw yield (difference of biomass and grain yields in Tables 3 and 4) of teff decreased from 94 % to 71 % and the straw yield of faba bean increased from 15 % to 66 % of the respective sole crop straw yield.

Table 3. Effects of mixed cropping on grain yields of teff and faba bean (kg ha^{-1}), teff yield equivalent (kg ha^{-1}) and land equivalent ratio (LER), 2002–2003.

	Grain yield			LER values		
Factor	Teff	Faba bean	Teff yield equivalent	Teff	Faba bean	Total
Year						
2002	849	917	1287	0.76	0.54	1.13
2003	1550	892	1851	0.85	0.51	1.19
Mean	1200	905	1569	1.61	0.81	1.16
s.e.	25.5	42.7	37.2	0.02	0.01	0.02
Mix-proportion (%)						
Sole teff	1480		1480	1.00		1.00
Sole faba bean		1586	1085		1.00	1.00
Teff/faba bean (100:12.5)	1362	341	1595	0.92	0.21	1.13
Teff/faba bean (100:25)	1262	584	1662	0.85	0.36	1.21
Teff/faba bean (100:37.5)	1165	767	1689	0.79	0.47	1.26
Teff/faba bean (100:50)	1016	948	1664	0.69	0.59	1.28
Teff/faba bean (100:62.5)	912	1147	1697	0.60	0.72	1.32
Mean	1200	893	1553	0.81	0.56	1.20
s.e.	44.2	74.6	69.5	0.04	0.05	0.04

Table 4. Effects of mixed cropping on agronomic traits and weed biomass of teff and faba bean grown in mixed and sole culture, 2002–2003.

	Total biomass (kg ha^{-1})		Plant height (cm)		Lodging (%)	WDM† (g m^{-2})	PPP† (no.)	SPP† (no.)
Factor	Teff	FB	Teff	FB	Teff	Teff/FB	FB	FB
Year								
2002	5741	2364	91	117	54	21	11.8	2.9
2003	8040	1918	93	91	53	47	8.0	2.3
Mean	6890	2141	92	104	53	34	9.9	2.6
s.e.	171	85.1	1.3	2.0	1.6	1.9	0.2	0.04
Mix-proportion (%)								
Sole	8140	4164	85	113	43	42(37)‡	10.0	2.7
Teff/FB (100:12.5)	7612	718	90	95	48	32	10.0	2.6
Teff/FB (100:25)	7039	1438	93	99	53	28	10.7	2.7
Teff/FB (100:37.5)	6620	1645	91	103	56	39	9.3	2.6
Teff/FB (100:50)	6263	2126	97	105	58	29	9.8	2.5
Teff/FB (100:62.5)	5670	2757	96	109	60	33	9.8	2.6
Mean	6891	2141	92	104	53	33.8	9.9	2.6
s.e.	297	147.4	2.3	3.5	2.8	3.3	0.4	0.1

† WDM = Weed dry matter; FB = Faba bean; PPP = Pods per plant; SPP = Seeds per pod.
‡ Figure in brackets is value for weed dry matter from sole faba bean.

Teff plants were shortest ($p \leq 0.01$) in the sole plot (Table 4). Teff plant height and thereby lodging tended to increase with increase in faba bean population in the mixed culture. Also, the faba bean plant height increased with increase in faba bean population attaining mean maximum height in the sole plots (Table 4). Weed biomass

Table 5. Relative crowding coefficient (k), product of the coefficients (K) and aggressivity (A), system productivity index (SPI) of teff and faba bean grown in mixed cultures.

	k value			A value		
Mix-proportion	Teff	Faba bean	K	Tef	Faba bean	SPI
Teff/faba bean (100:12.5)	1.44	2.19	3.15	−0.80	0.80	1680
Teff/faba bean (100:25)	1.45	2.33	3.38	−0.60	0.60	1807
Teff/faba bean (100:37.5)	1.39	2.50	3.48	−0.50	0.50	1881
Teff/faba bean (100:50)	1.10	2.97	3.27	−0.50	0.50	1901
Teff/faba bean (100:62.5)	1.00	3.01	3.01	−0.60	0.60	2032
Mean	1.28	2.60	3.33	−0.60	0.60	1860

was the highest in sole teff plots. The panicle size of teff, and the number of pods per plant, seeds per pod, seed weight and nodule number of faba bean were not affected by intercropping treatments. Grain and biomass yield of teff was significantly ($p \leq 0.01$) greater in 2003 than in 2002 (Table 4). Seed yields of faba bean were similar in the two years. The year by treatment interaction effects were not significant for grain yields of the component crops.

Resource use efficiency and competitive ability

Differences among treatments were highly significant ($p \leq 0.001$) for partial and total LERs. The partial LERs in mixed cultures ranged from 0.60 to 0.92 for teff and from 0.21 to 0.72 for faba bean producing a range of 1.13 to 1.32 for the total LER (Table 3). The highest value (1.32) was obtained from the binary combination of 100:62.5 teff:faba bean (Table 3). The growing season had a highly significant ($p \leq 0.01$) influence on partial LERs of teff. The year by treatment interaction effects were not significant for partial and total LERs, implying that the sole and mixed cultures did not respond differently to the treatments over the two growing seasons.

Increase in faba bean seed rate in mixtures increased k for faba bean but decreased the values for teff (Table 5). The k values for faba bean were the highest in the 100:62.5 mixture, in which total yield, LER and SPI were also the highest. The total LER was positively related to the total grain yields of the two crops (Figure 1); The aggressivity parameter (A) indicated a tendency for faba bean to dominate teff in mixtures (Table 5 and Figure 2).

DISCUSSION

Although the seed yields of the component crops were low compared to their respective sole crop yields, the total land productivity was improved in mixed cultures as supported by the total LER values. Similar results have been reported for mixed cultures of wheat and field bean (Bulson *et al.,* 1997; Hauggaard-Neilsen and Jensen, 2001; Haymes and Lee, 1999) and pea and barley (Jensen, 1996). Despite this, the total straw portion of the intercrop was less than that of sole teff. Since teff straw is the preferred crop residue used as livestock feed, the implication of this in total economic return and its impact on adoption of teff/faba bean mixed cropping in the central highlands of Ethiopia needs to be assessed further.

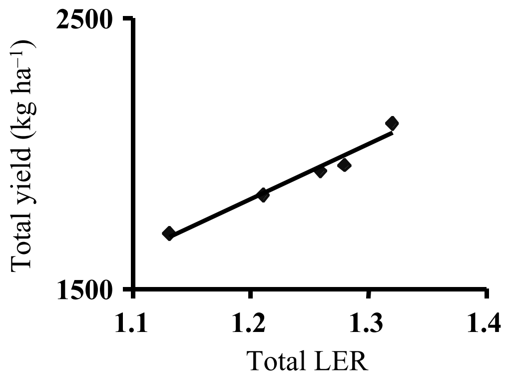

Figure 1. Relationship between total grain yield (kg ha^{-1}) and total land equivalent ratio (LER) of teff and faba bean in mixed culture. Y = −708(642) + 2186(535)X, r^2 = 0.85.

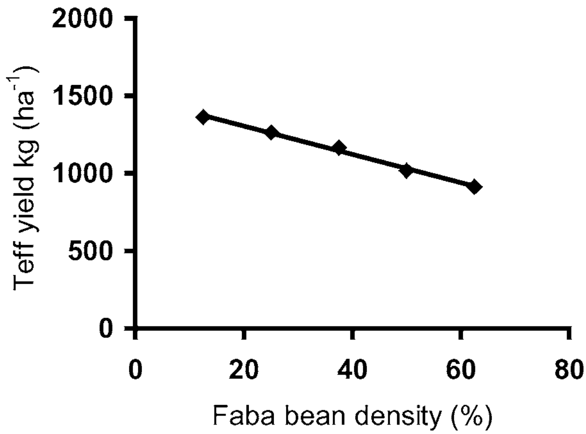

Figure 2. Relationship between teff yield (kg ha^{-1}) and faba bean density in mixed culture. Y = 1487(16.7) − 9.2(0.40)X, r^2 = 0.99.

Mixed cropping of faba bean in teff reduced weed biomass to below that observed in sole teff, which agrees with the findings of Bulson *et al.* (1997) for wheat/field bean mixed cropping. Broad leaf weeds in teff are a significant agronomic problem in the central highlands of Ethiopia. Teff weeds in the region are often controlled using broad leaf herbicides, notably 2, 4-D. Since this herbicide also acts against faba bean, weed control in the mixture hinges on cultural rather than chemical methods. As a result, the increased suppression of weeds in the mixture may ease the demand on labour for manual weed control and thereby enhance the likelihood of adoption of teff/faba bean mixed cropping.

On average, grain yields were lower in 2002 than in 2003 for teff but not for faba bean, perhaps because of differences in the flowering times of the two crops, which were 24 August for faba bean and 10 September for teff. Later flowering for teff means more exposure to late season moisture stress during the critical time of grain filling particularly during the drier months of September and October in 2002. In this study, the fact that yields of only one of the two crops was affected in 2002 further supports the buffering advantage of crop mixtures during years of adverse weather in unpredictable environments, such as those common in East Africa.

Faba bean plant height increased with the faba bean population, reaching its maximum in sole culture. This is to be expected as the taller and robust faba bean plants compete for light in dense stands. The plant height of teff also increased as the population density of faba bean in the mixture increased. Competition between the component crops for resources is also reflected in the k values of the crops that increased for faba bean but decreased for teff with increases in faba bean density in the mixture. According to Willey (1979), a species has a k value less than, equal to, or greater than unity when it produces less, the same or more yield than 'expected' respectively. The k values for teff in this study declined rapidly equalling unity with increases in faba bean density to 62.5 % of the sole crop. Further increases in faba bean density are likely to give less teff yield than expected, implying further domination of teff by faba bean. Even with the faba bean densities used in this study, the relatively low k and negative A values for teff indicate the suppression of teff by faba bean. In the future, it may be important to evaluate up to 100 % addition of faba bean in full seed rate culture of teff.

One of the prime objectives of contemporary intercropping studies is to assess the N economy of the component crops. The present study is deficient in this aspect and, therefore, future studies should assess the extent of N capture accruing from intercropping. In Ethiopia, both teff and faba bean are high value crops required for both domestic and export markets. Sustainable maximization of economic yields of these crops is one of the cardinal goals of research and extension mandates in the country. A teff/faba bean intercropping system could be economically and environmentally propitious in the Ethiopian highlands, a region characterized by high population density, small farm size and low farm income. The complementary use of nutrient and water sources by the intercrop components and the need for reduced external inputs resulting from cereal/pulse mixed cropping are auspicious, calling for further attention from research and development stakeholders in the Ethiopian highlands. Meanwhile, from this study, we propose that mixed cropping of faba bean in full teff culture at a density not exceeding 62.5 % of the sole faba bean culture may improve overall yields and incomes.

Acknowledgement. We acknowledge the Food Legumes Project, sponsored by the Netherlands Government and the Ethiopian Institute of Agricultural Research for funding this experiment. Due regards are to Dr. Nigussie Alemayehu for his comments on the manuscript and Mr. Beyene Ofa for his assistance in the execution of the experiment.

REFERENCES

Anil, L., Park, J., Phipps, R. H. and 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 and Forage Science* 53:301–317.

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

Bulson, H. A. J., Snaydon, R. W. and Stopes, C. E. (1997). Effects of plant density on intercropped wheat and field beans in an organic farming system. *Journal of Agricultural Science* Cambridge 128:59–71.

Caldicott, J. J. B. and Nuttall, A. M. (1979). A method for the assessment of lodging in cereal crops. *Journal of National Institute of Agricultural Botany* 15:88–91.

Central Statistics Authority (CSA). (2004). Agricultural sample survey: Report on area under cultivation yield and production of the major crops. *CSA, Addis Ababa, Ethiopia.*

Chu, G. X., Shen, Q. R. and Cao, J. L. (2004). Nitrogen fixation and N transfer from peanut to rice cultivated in aerobic soil in intercropping system and its effect on soil N-fertility. *Plant and Soil* 263:17–27.

Dapaah, H. K., Asafu-Agyei, J. N., Ennin, S. A. and Yamoah, C. Y. (2003). Yield stability of cassava, maize, soybean and cowpea intercrops. *Journal of Agricultural Science* Cambridge 140:73–82.

Georgis, K., Abebe, A., Negasi, A., Dadi, L. and Sinebo, W. (1990). Cereal/legume intercropping research in Ethiopia. *Proceedings of a Workshop on Research Methods for Cereal/Legume Intercropping in Eastern and Southern Africa*, 167–175. Mexico, CIMMYT.

Hauggaard-Nielsen, H. and Jensen, E. S. (2001). Evaluating pea and barley cultivars for complementarity in intercropping at different levels of soil N availability. *Field Crops Research* 72:185–196.

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

Hiebsch, C. K. and McCollum, R. E. (1987). Area-×-time equivalency ratio: A method for evaluating the productivity of intercrops. *Agronomy Journal* 79:15–22.

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.

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. *Experimental Agriculture* 27:435–441.

Ofori, F. and Stern, W. R. (1987). Cereal-legume intercropping systems. *Advances in Agronomy* 41:41–90.

SAS Institute. (2001). SAS/STAT User's Guide, Version 8.2. *SAS Institute Inc., Cary, NC, USA.*

Willey, R. S. (1979). Intercropping – its importance and research needs. Part 1. Competition and yield advantages. *Field Crop Abstracts* 32:1–10.