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Interactions of bush bean intercropped with field and sweet maize

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Abstract

Common bean, *Phaseolus vulgaris* L., is traditionally intercropped with maize by small-scale farmers in northwest Spain. Interactions of genotypes of beans with cropping systems and seasons were studied to determine if selection of bean in sole cropping would be a valid approach to genetic improvement for intercropping. In this experiment, 10 dry bush bean varieties were evaluated in sole cropping and intercropping with two types of maize (field and sweet maize) at two locations for 2 years. The performance of bean genotypes in each cropping system was compared with respect to developmental plant characteristics, seed yield and yield components and food quality traits. A significant bean genotype × cropping system interaction was found for period of flowering and seed yield, and there were significant differences between cropping systems for pods per plant, seed length and seed coat proportion. Intercropping with field maize reduced bean yield by 55% and intercropping with sweet maize reduced bean yield by 44%. Significant and high correlations of bean yields were obtained between sole cropping and intercropping with maize. Mean yields were used to calculate the land equivalent ratios (LERs), which averaged 1.12 for intercropping with field maize and 0.93 for intercropping with sweet maize. Specific variety combinations reached LER values greater than one. Net income was higher for some intercrop patterns than for bush bean sole crop. The most competitive bean varieties yielded the most when intercropped with maize but those varieties were not necessarily the highest yielding in sole cropping. The most competitive bean varieties were the latest to flower. The evaluation of bush bean genotypes for agronomic and food quality traits under sole cropping provides sufficient information to select varieties efficiently for the field maize-bean and sweet maize-bean intercropping systems. Greatest net income was realized when bush beans intercropped with sweet maize, provided a system with higher added value compared to intercropping with field maize. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Intercropping; *Phaseolus vulgaris*; *Zea mays*; Quality; Yield; LER

1. Introduction

Common bean (*Phaseolus vulgaris* L.) is potentially the most valuable source of plant protein for human consumption in many parts of south Europe and contributes significantly to the sustain-

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ability of traditional cropping systems, because of the predominance of small-scale farmers who cultivate bean in these areas (Moreno et al., 1985; Santalla et al., 1994; FAO, 1997). Approximately, 40% of the cultivated land in Spain is used for intercropping, 42 10^3 ha in intercrop compared to 10.7 10^3 ha in sole crop in 1995, although it has been decreasing up to 13.5 10^3 ha in intercrop in 1997 (MAPA, 1999). One of the most common cropping systems combines common bean with maize (*Zea mays* L.). The farmer's primary objective is to produce a high yield of the maize crop. A secondary objective is to produce a good bean yield. The yield effectiveness of an intercrop is valued with the concept of a land equivalent ratio (LER) which is used to obtain evidence as to whether two or more crops should be intercropped rather than planted as sole crops (Mead and Willey, 1980; Vandermeer, 1989).

The socioeconomical peculiarities of northwest Spain, the use of traditional varieties grown in small holdings by the own supplying or sale in local markets, have made possible the maintenance of a considerable agricultural diversity. As a consequence of a modern agriculture, the intercropped practices are being replaced by sole crops of maize hybrids and improved bean varieties. A large majority of traditional bean varieties have been replaced by modern varieties which are economically more viable, but with a narrow genetic base, and for improved varieties imported from other countries, but with a lower seed quality than the local bean varieties. These improved varieties are invariably selected for performance under sole crop conditions and the intercrop systems do not do so well as they do with local bean varieties that have been selected to perform under a different set of conditions (Vandermeer, 1989).

In intercropping, farmers attach importance not only to crop yield but also to economic values. There are different cropping systems according to the farmer's requirements. One common situation is when the farmer is concerned about only one of the two crops. The intercrops should be compared to the most valuable of the two sole crops. The most valuable crop must be favoured in the system, while it is desirable to preserve the other crop component to give an adequate return from the total system, increase production stability and thus reduce risk. Another situation is when the farmer requires particular mixtures, either because of market conditions, labour management, or dietary requirements (Vandermeer, 1989). In northwest Spain, beans are intercropped with maize because the bean plants take advantage of the maize stalks to climb and the maize is mostly used for the local feed consumption. In this situation, a maize crop which can be used as vegetable would give the highest economic returns from the cropping system without main modifications to traditional agronomic practices. Bean varieties intercropped in both situations should be selected for seed size, colour and cooking time. These physical properties influence consumers preferences (Adams and Bedford, 1973), although nutritional quality is also becoming increasingly important (TR-02, 1999).

The increasing concern on agricultural sustainability favours the maintenance of intercropping systems, which constitute a risk insurance for the small farmers offering several biological and socioeconomic advantages (Willey, 1979; Baudoin et al., 1997). Although intercropping is often more profitable (Francis and Sanders, 1978) and may be favoured for sustainable farming, bean yield reductions occur with intercropping for varieties of all growth habits (Clark and Francis, 1985). In spite of progress in recent years (Santalla et al., 1994; Zimmermann, 1996), breeding beans for multiple cropping systems faces major challenges. The objectives of this study were to determine the importance of dry bush bean variety by cropping system interactions to variety selection for the field maize-bean and sweet maize-bean intercropping, and to determine how best to select beans for the intercropping systems.

2. Material and methods

2.1. Plant material

Ten bush bean varieties representing local grain types were used. These accessions were adapted to the bean production areas of northwest Spain, and they included two large white-seeded *Gar-*

banzo de Piñon (PHA-0013 and PHA-0014), three medium white-seeded *Garbanzo* (PHA-0009, PHA-0012, PHA-0016), one small white-seeded *Chichos blancos* (PHA-0471), one medium white-seeded *Redonda* (PHA-0065), one medium light tan-seeded *Garbanzo* (PHA-0041), one medium seeded *Pinta* (PHA-0057) and one large kidney-seeded *Pinta* (PHA-0104) type. These accessions consisted of landraces which can be considered as unimproved populations since they have been maintained as a mixture of pure lines by farmers during generations. They were collected in areas where traditional farming methods have encouraged the presence of old varieties. This genetic material is maintained in the germplasm collection at the Mision Biologica de Galicia (Ron de et al., 1997). The maize cultivars used in intercropping were a field maize hybrid *Eva* (20 cm ear length and 9728 kg/ha of grain yield) with a FAO 200 maturity rating, and a sweet maize hybrid *Rodeo* (13 cm ear length and 1950 kg/ha of grain yield), with an optimum harvest period for fresh grain consumption about 100 days from planting. These maize cultivars are currently recommended for these areas.

2.2. Experimental design

Field experiments were done at two locations in northwest Spain, Pontevedra (42°24′ N latitude 8°38′ W longitude, 40 m altitude, 14°C mean temperature, average rainfall 1608 mm) and La Coruña (43°14′ N latitude 8°16′ W longitude, 20 m altitude, 13°C mean temperature, average rainfall 974 mm) in two consecutive years (1993 and 1994). Fertilizer application of 160 kg of N/ha, 120 kg of P/ha and 200 kg of K/ha was applied just prior to sowing and 50 kg of N/ha was top dressed 30 days after planting. Diseases and pests were controlled as far as possible in all trials, and irrigation was supplied when necessary.

A split-plot design with two replications was used where cropping systems (bean sole crop, intercrop of bean with field maize and intercrop of bean with sweet maize) were the main plots and the 10 bush bean varieties were the subplots. In sole cropping main plots, the experimental subplots were six rows of bean with row to row distance of 50 cm and 3 m long, and thinned to an experimental density of 80 000 plants ha^{-1}. The intercropping main plots were identical except that a row of maize (field or sweet maize) replaced a bean row, and consisted of simultaneous sowing of maize and bean. Mature beans and maize were harvested about 100 and 200 days, respectively, from planting and the grain was maintained in a storage room at 0 ± 2°C and 50% humidity.

2.3. Data analysis

Developmental plant data included, days to flowering, end of flowering, period of flowering and days to maturity. The yield and yield components determined were: number of pods per plant, number of seeds per pod and bean and maize yield adjusted to 14% moisture (Santalla et al., 1994). Food quality data were measured on dried, soaked and cooked bean seeds. These included, dry and soak seed weight, seed length and width, seed hardness, seed volume, proportion of seed coat, water absorption (Santalla et al., 1995; Escribano et al., 1997), crude protein, crude fat, starch, total sugars and moisture which were determined using Near Infrared Transmittance (Williams et al., 1978; Rudzik, 1990).

Combined analysis of variance appropriate for a split-plot design (mixed model) was conducted as per Gomez and Gomez (1984), using the general lineal model (GLM) procedure of the SAS statistical package (SAS Institute, 1990). Locations and years were considered as random effects, while cropping systems and varieties were fixed in the model. The least significant difference (LSD) method ($P < 0.05$) was used to evaluate differences between variety and cropping system means. Simple and Spearman rank correlation coefficients between traits which presented a significant genotype by cropping system interaction were obtained for each pair of seasons and between cropping systems in each season. The land equivalent ratio (LER) was used to assess the performance of an intercrop relative to the corresponding sole crop (Mead and Willey, 1980).

$LER = {}^{n}\sum_{j} = 1 y_{j,i}/y_{j,s}$

where $y_{j,i}$ is the yield of component crop j in intercropping, and $y_{j,s}$ is the yield of the crop in sole cropping. LER values > 1.0 indicate a total yield advantage of growing intercrops over sole crops, since the index denotes how much land would be required for growing sole crops to obtain the same yields of each component as was obtained in intercropping. LER values > 1.0 also provide evidence of complementary resources use between the two components of the intercrops.

3. Results

Analyses of variance for agronomic and food quality traits are shown in Tables 1 and 2. There were significant differences among cropping systems for pods per plant, seed length and seed coat proportion. Cropping system × variety interaction was only significant for the period of flowering and seed yield. The combined analysis of bean varieties over four seasons and three cropping systems gave a significant variety × cropping system × season interaction for days to flowering, end of flowering, seed yield and seed width. The cropping system x season interaction was significant for seed coat proportion. Significant genotypic differences were observed for most of the traits studied except for period of flowering, days to maturity, pods per plant and seed hardness in the combined analysis. The variety × season interaction was not significant for days to maturity, pods per plant, seed hardness, seed moisture, crude fat and total sugars. Significant season (years or locations) differences were observed for days to flowering, period of flowering, seed width, dry seed weight, water absorption, seed coat proportion, crude protein and crude starch.

Means are presented for each cropping system for all traits studied (Tables 1 and 2) and for each variety for days to flowering, end of flowering, period of flowering, number of pods per plant and seed yield (Table 3). The yield component of number of pods per plant and the quality traits of seed length and coat proportion showed different responses to the cropping systems. Number of pods per plant of all bean varieties was greater in sole cropping and intercropping with sweet maize than in intercropping with field maize. Seed size was longer in intercropping with field maize compared to the other cropping systems, while seed coat proportion was slightly less in that cropping system. The bean variety PHA-0009 presented almost identical plant development in intercropping compared to sole cropping. However, the bean varieties PHA- 0013, PHA-0016, PHA-0041, PHA-0065 and PHA-0104 had periods of flowering ranged from 18 to 21 days in sole cropping while in intercropping with field and sweet maize they were about 15 and 17 days, respectively. On the other hand, the bean varieties PHA-0012, PHA-0014, PHA-0057 and PHA-0471 had periods of flowering ranged from 14 to 17 days in sole cropping but in intercropping with field and sweet maize they were up to 19 and 17 days, respectively. The highest yield reduction by intercropping was detected in the bean varieties PHA-0065 and PHA-0104. No yield reduction was furthermore found with the bean varieties PHA-0012 and PHA-0057 when intercropped.

Correlations of yields, flowering periods and ranks are summarized in Tables 4 and 5 for bean varieties which were planted in common over each pair of seasons, in sole cropping, intercropping with field maize and intercropping with sweet maize. Most of the pair of seasons evaluated in each cropping system showed low values of correlations for bean yield and period of flowering.

Simple correlations were calculated for yields, flowering periods and ranks between each pair of cropping systems (Tables 6 and 7). Correlations of yields between sole crop and intercropping with field maize ranged from 0.52* to 0.66*, and between sole crop and intercropping with sweet maize ranged from 0.88** to 0.91*. Correlations between ranks across sole cropping and intercropping with sweet maize were similar to the correlations for yield, but between sole crop and intercropping with field maize were higher than the correlations for yield. Correlations of periods of flowering between cropping systems were low.

Land equivalent ratio values (LERs) are showed in Table 8, which averaged 1.12 in intercrop with field maize and 0.93 in intercrop with sweet maize. LERs > 1.0 were found in intercropping with field

Table 1
Combined analyses of variance of developmental plant and yield traits of the common bean varieties from northwest Spain in sole crop, intercrop with field maize and intercrop with sweet maize

Character	D.F.	Days to flowering (days)	End of flowering (days)	Period of flowering (days)	Days to maturity (days)	Pods per plant	Seeds per pod	Seed yield (kg/ha)
Years (Y)	1	6285.3*	1265.4	1550.6**	0.0	164.2	34.44	8 575 484.4
Locations (L)	1	50.8	1125.0	844.9**	4876.9	31.7	20.54	11 257 889.5
Y × L	1	1008.0	434.0	59.8	0.0	372.0	0.00	7 246 988.9
Replications (Y × L)	4	828.4	1028.4	31.8	1584.4	63.2	6.97	40 020 777.5
Cropping systems (S)	2	215.2	339.4	16.0	321.3	85.4*	0.06	13 880 861.5
S × Y	2	101.3	78.2	6.2	0.0	29.8	0.31	3 082 523.2
S × L	2	187.5	192.7	4.9	231.3	15.7	0.75	1 665 676.3
S × Y × L	2	95.2	93.3	60.7	0.0	15.7	0.00	0.0
Error a	8	196.7	176.1	29.3	264.5	17.5	0.32	6 152 318.7
Varieties (V)	9	239.9**	154.1**	24.8	9.7	23.5	1.64**	39 663 618.3**
V × Y	9	192.3**	158.1**	10.9	0.0	36.7	1.33**	239 135.7
V × L	9	92.3**	48.0*	38.9**	15.2	9.2	0.65*	3 279 779.6**
V × Y × L	9	82.6*	107.4**	11.3	0.0	13.0	0.00	3 451 19.7
V × S	18	38.2	30.1	25.4*	23.9	15.0	0.27	1 520 290.7*
V × L × S	18	57.9*	56.6**	16.5	16.9	8.1	0.42	2 671 689.6*
V × Y × S	18	19.4	12.5	15.2	0.0	17.1	0.37	228 463.2
V × L × Y × S	16	42.4	31.5	6.1	0.0	22.6	0.00	0.0
Error b	94	28.3	22.0	14.3	22.3	27.3	0.28	835 938.1
Mean		50.8	67.2	16.5	111.4	9.4	4.56	1433
Sole crop		52.5	69.6	17.1	114.6	10.9	4.60	2169
Intercrop field maize		49.9	65.6	16.0	110.5	7.1	4.57	982
Intercrop sweet maize		50.1	66.5	16.5	109.1	10.7	4.51	1207
LSD (5%)		ns	ns	ns	ns	1.9	ns	ns

D.F., Degrees of freedom. * Significant at $P < 0.05$; ** Significant at $P < 0.01$; ns, not significant. Error a = Replications × Cropping systems (Years × Locations). Error b = Replications × Varieties (Years × Locations) + Replications × Cropping systems × Varieties (Years × Locations).

Table 2
Combined analyses of variance of food quality traits of the common bean varieties from northwest Spain in sole crop, intercrop with field maize and intercrop with sweet maize

Character	D.F.	Seed length (cm)	Seed width (cm)	Seed volume (cm^3)	Dry seed weight (g)	Soak seed weight (g)	Hardness (1/10 mm)	Water adsorption (%)	Coat proportion (%)	Seed moisture (%)	Crude protein (%)	Crude fat (%)	Crude starch (%)	Total sugars (%)
Years (Y)	1	39.89	0.083	155.45	1805.41**	14 920.11	25.67	4377.53**	22.55**	0.358	8.64*	0.021	20.27**	0.032
Locations (L)	1	15.36	0.892*	13 255.30	1136.32**	13 924.23	82.42	1826.39**	3.82*	0.281	6.52	0.003	6.16*	0.037
Y × L	1	0.53	0.743*	9121.58	532.37*	9701.25	31.81	1201.22**	0.09	0.062	1.05	0.005	0.00	0.114
Replications (Y × L)	4	15.99	0.086	3903.93	31.11	5416.39	27.09	16.15	0.38	0.064	0.95	0.003	0.55	0.039
Cropping systems (S)	2	2.87*	0.216	504.07	3.50	15.35	4.64	3.84	2.12*	0.060	0.18	0.012	0.82	0.020
S × Y	2	2.86	0.046	1308.62	26.87	117.27	26.21	12.96	0.15	0.038	0.06	0.006	0.12	0.027
S × L	2	0.86	0.164	1105.88	17.38	18.26	24.25	125.17	0.46	0.041	0.05	0.004	0.49	0.015
S × Y × L	2	0.59	0.235	276.45	32.89	47.39	7.95	88.89	1.45*	0.066	0.08	0.001	0.16	0.000
Error a	8	0.65	0.094	993.79	13.09	56.38	48.48	128.76	0.26	0.043	0.27	0.003	0.42	0.077
Varieties (V)	9	228.99**	16.308**	20 873.94**	6506.79**	26 301.81**	12.08	414.90**	9.74**	0.198**	7.62**	1.629**	5.70**	2.755**
V × Y	9	1.71	0.483**	589.08**	311.76**	1655.48**	23.88	32.35	1.69*	0.014	0.97**	0.006	2.10**	0.037
V × L	9	2.54*	0.317**	1697.46**	190.44**	1001.01**	29.75	28.21	0.32	0.045	0.67*	0.003	1.47**	0.069
V × Y × L	9	1.10	0.169**	419.00*	21.79	258.69**	19.61	52.77*	0.31	0.015	0.40	0.002	0.93	0.008
V × S	18	1.07	0.074	128.90	11.51	51.41	22.36	31.77	0.56	0.030	0.26	0.006	0.56	0.021
V × L × S	18	0.44	0.056	63.98	8.27	26.11	23.01	17.27	0.36	0.041	0.19	0.002	0.29	0.014
V × Y × S	18	1.47	0.107**	133.66	10.61	38.91	10.28	20.95	0.78	0.039	0.39	0.010	0.71	0.046
V × L × Y × S	16	0.76	0.078	176.57	8.23	18.42	6.56	42.43	1.02	0.022	0.73	0.012	0.15	0.001
Error b	94	0.97	0.050	155.39	12.52	67.44	17.90	23.02	0.66	0.025	0.28	0.007	0.36	0.077
Mean		2.34	7.74	73.9	44.9	86.56	34.5	103.0	7.53	12.313	26.46	1.536	44.08	4.47
Sole crop		12.43	7.71	68.8	44.1	84.50	34.3	103.8	7.67	12.385	26.59	1.543	43.99	4.48
Intercrop field maize		12.49	7.80	76.9	46.0	89.54	34.7	102.0	7.32	12.264	26.34	1.544	44.13	4.43
Intercrop sweet maize		12.10	7.69	76.3	44.6	85.74	34.5	103.4	7.61	12.286	26.45	1.519	44.14	4.50
LSD (5%)		0.31	ns	ns	ns	ns	ns	ns	0.20	ns	ns	ns	ns	ns

D.F., Degrees of freedom. Error a = Replications × Cropping systems (Years × Locations). Error b = Replications × Varieties (Years × Locations) + Replications × Cropping systems × Varieties (Years × Locations). * Significant at $P < 0.05$; ** Significant at $P < 0.01$; ns,not significant.

Table 3
Means, standard errors (SE), coefficients of variation (CV) of developmental plant and yield traits of the common bean varieties from northwest Spain in sole crop (S), intercrop with field maize (IF) and intercrop with sweet maize (IS)

Variety	Days to flowering (days)			End of flowering (days)			Period of flowering (days)			Pods per plant			Seed yield (kg/ha)		
	S	IF	IS	S	IF	IS	S	IF	IS	S	IF	IS	S	IF	IS
PHA-0009	56.6	56.5	56.6	71.9	70.6	71.9	15.3	14.1	15.3	12.1	7.7	11.5	1379	576	1393
PHA-0012	54.4	51.3	53.5	68.4	66.5	69.9	14.0	15.2	16.4	7.6	8.0	13.5	1064	1836	1006
PHA-0013	50.8	51.1	48.9	70.6	66.5	65.6	19.9	15.4	16.8	9.6	5.0	9.7	2214	563	1596
PHA-0014	53.4	47.8	48.6	70.8	66.4	65.4	17.4	18.6	16.8	11.8	7.6	7.3	2479	562	812
PHA-0016	49.2	53.5	53.2	70.4	65.1	70.0	21.2	15.0	16.8	8.8	8.3	12.6	1368	1116	654
PHA-0041	54.5	48.4	46.6	73.4	63.8	64.3	18.9	15.4	17.7	12.2	4.9	11.3	1209	740	842
PHA-0057	53.0	46.6	50.5	66.7	64.0	66.9	13.7	17.4	16.4	10.1	3.7	7.2	1323	1357	2262
PHA-0065	47.8	48.3	45.1	65.3	64.0	62.6	17.5	15.8	17.5	11.5	7.9	11.1	2998	765	491
PHA-0104	47.1	47.5	47.1	65.0	61.5	64.0	17.9	14.0	16.9	13.6	7.4	8.9	4132	1341	1475
PHA-0471	57.4	48.8	51.6	73.1	67.5	64.9	15.8	18.9	14.6	11.3	10.6	15.7	1812	964	1063
LSD (5%)	6.4	5.0	5.2	4.2	5.2	5.2	4.8	3.2	3.8	7.6	3.7	7.6	1867	1238	756
SE	2.13	1.72	1.78	1.41	1.76	1.76	1.61	1.08	1.27	2.14	1.09	2.05	425.5	304.9	164.7
CV (%)	11.49	9.74	10.05	5.73	7.61	7.50	26.70	19.18	21.73	55.83	43.68	54.28	55.52	87.90	38.60

maize with the bean varieties PHA-0009, PHA-0012, PHA-0016, PHA-0041, PHA-0057 and PHA-0471, while in intercropping with sweet maize, the values of LER > 1.0 were detected with the bean varieties PHA-0009, PHA-0012, PHA-0013, PHA-0041 and PHA-0057.

4. Discussion

The low values of the correlation coefficients for most of the pair of seasons evaluated and the variety × season interaction observed in the experiment for seed yield and period of flowering confirm the strong seasonal influence on these traits and ordering of bean genotypes and could complicate the breeder's quest for genetic progress and yield stability. These values of correlation must be taking into account to select elite bean varieties for further testing. Further analyses of more bean genotypes and seasons would be necessary to explore the magnitude of these interactions.

The low and negative correlation values detected for period of flowering between sole cropping and intercropping and the significant cropping system x variety interaction found in the experiment suggest that the flowering performance of the bean varieties differed with the cropping system. The bean varieties PHA-0013, PHA-0016, PHA-0041, PHA-0065 and PHA-0104 had longer periods of flowering in sole cropping (ranged from 18 to 21 days) than in intercropping with field maize (by 15 days) and in intercropping with sweet maize (by 17 days). The reduction in the duration of flowering by intercropping with field maize in those bean varieties was up to 6 days and by intercropping with sweet maize was up to 4 days. On the other hand, the bean varieties PHA-0012, PHA-0014, PHA-0057 and PHA-0471 had longer periods of flowering in intercropping (ranged from 17 to 19 days) than in sole cropping (ranged from 14 to 17 days). The increase in the duration of flowering by intercropping with field maize was up to 3 days and by intercropping with sweet maize was up to 2 days. The reduction in the period of flowering by intercropping was observed in the earliest to flower bean varieties. In addition, the field maize crop was more competitive on bean flowering than it was the sweet maize crop.

Results of four seasons of testing bush beans in three contrasting cropping systems demonstrated a significant interaction of variety × cropping system for seed yield although a significant correlation between bean yields of sole crop and intercrop was observed. The greatest reduction in bean yield occurred in intercropping with field maize (55%) than in intercropping with sweet maize (44%) but it was not consistent across all bean varieties. Bean varieties PHA-0012 and PHA-0057 did not have as great a yield reduction in intercropping as the other bean varieties. Bean varieties PHA-0065 and PHA-0104 had the highest reduction in yield when intercropped and

Table 4
Simple correlations and Spearman's coefficient of rank correlations of common bean yields across trials

Comparison	*r*-values between seasons					
	Sole cropping		Intercropping with field maze		Intercropping with sweet maize	
	Yield	Rank	Yield	Rank	Yield	Rank
Trial 1 vs. Trial 2	0.99	0.99	0.13	0.07	0.00	0.00
Trial 1 vs. Trial 3	0.12	0.37	0.19	0.19	−0.32	−0.46
Trial 1 vs. Trial 4	0.28	0.43	0.91**	0.75*	0.68	0.49
Trial 2 vs. Trial 3	0.00	0.00	0.52	0.80	0.00	0.00
Trial 2 vs. Trial 4	0.00	0.00	−0.05	0.10	0.00	0.00
Trial 3 vs. Trial 4	0.38	0.11	−0.12	0.14	0.27	0.20

Trial 1, Pontevedra-1994. Trial 2, Mabegondo-1994. Trial 3, Pontevedra-1995. Trial 4, Mabegondo-1995. * Significant at $P<0.05$; ** Significant at $P<0.01$.

Table 5
Simple correlations and Spearman's coefficient of rank correlations of common bean periods of flowering

Comparison	*r*-values between seasons					
	Sole cropping		Intercropping with field maze		Intercropping with sweet maize	
	Flowering	Rank	Flowering	Rank	Flowering	Rank
Trial 1 vs Trial 2	0.11	0.09	0.41	0.45*	−0.12	−0.06
Trial 1 vs Trial 3	−0.37	−0.41	0.10	0.19	−0.27	−0.22
Trial 1 vs Trial 4	0.18	0.22	−0.16	−0.14	0.25	0.06
Trial 2 vs Trial 3	−0.17	0.01	0.13	0.11	−0.31	−0.38
Trial 2 vs Trial 4	0.72**	0.76**	0.32	0.23	−0.44	−0.48*
Trial 3 vs Trial 4	−0.01	0.01	0.18	0.19	0.10	0.15

Trial 1, Pontevedra-1994. Trial 2, Mabegondo-1994. Trial 3, Pontevedra-1995. Trial 4, Mabegondo-1995. * Significant at $P<0.05$; ** Significant at $P<0.01$.

they were also the most yielding under sole cropping. The bean varieties with the lowest bean yield reduction in intercropping were the latest to flowering, which is agreement with Davis and Garcia (1983). In addition, these bean varieties had the shortest duration of flowering in sole cropping which was increased by intercropping. Significant differences between cropping systems and high positive correlations between sole cropping and intercropping for seed yield were also observed by Francis et al. (1978), who showed the number of pods per plant was reduced by intercropping in approximately the same proportion as the reduction in yield. This result does not agree with that of Willey and Osiru (1972), who found that the lower yield per plant was largely due to a decrease in only one component, the number of seeds per pod rather than the number of pods per plant. Adams (1967) and Atuahene-Amankwa and Michaels (1997) found the number of pods per plant to be the component most readily affected by competition. Most of the yield reduction observed in this work in the bush bean varieties due to intercropping could be accounted by fewer pods per plant under the maize crop.

There were no benefits of intercropping with either maize crop (Table 8), with values of LER < 1.0, with the bean varieties PHA-0014, PHA-0065 and PHA-0104. The largest benefits of intercropping with field maize were found with the bean varieties PHA-0009, PHA-0012, PHA-0016, PHA-0041, PHA-0057 and PHA-0471, while of intercropping with sweet maize were observed with the bean varieties PHA-0009, PHA-0012, PHA-0013, PHA-0041 and PHA-0057. The maximum LER values in each intercropping system indicated greater efficiency in this specific intercrop combination compared to sole cropping in the experimental conditions used.

On the basis of prices and variable costs, which included labour but no cost for land, a simple economic analysis of the results was made (Table 8). Gross incomes from bean sole cropping and intercropping systems were computed, assuming a large-medium dry bean price of 2.40 €/kg, a field maize price of 0.18 €/kg and a sweet maize price of 4.09 €/kg in Spain in 2001. Production costs estimated for each system on the Spanish farm ranged from 1442 €/ha for bush bean sole cropping to 1774 €/ha for maize and bean intercropping. The highest gross and net returns were realized from dry bean varieties PHA-0012 and PHA-0057 associated with field maize and from dry beans PHA-0009, PHA-0012, PHA-0013 and PHA-0057 associated with sweet maize. The highest economic returns realized in intercropping with field maize with some dry bean varieties were similar to the average income value of the bean sole cropping. However, the highest economic returns of the bean–sweet maize intercropping systems were superior to the average income value of the bean sole cropping.

This study indicates that the most economically satisfactory intercropping system was obtained

Table 6
Simple correlations and Spearman's coefficient of rank correlations of common bean yields across cropping systems

Comparison	*r*-values between seasons							
	Trial 1		Trial 2		Trial 3		Trial 4	
	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank
Sole crop vs Field intercrop	0.52*	0.55*	0.00	0.00	0.66*	0.58	0.77	0.90*
Sole crop vs Sweet intercrop	0.13	0.14	0.00	0.00	0.88**	0.61*	0.91*	0.99**
Field intercrop vs Sweet intercrop	0.64**	0.52*	0.00	0.00	0.91**	0.69*	0.93*	0.90*

Trial 1, Pontevedra-1994. Trial 2, Mabegondo-1994. Trial 3, Pontevedra-1995. Trial 4, Mabegondo-1995. * Significant at $P<0.05$; ** Significant at $P<0.01$.

with the latest flowering bean varieties which gave good bean yields in intercropping and they would produce the highest net income. On the other hand, there was no relationship between yield potential in sole cropping and competitive ability in intercropping. Differences in the flowering periods between both cropping systems and across bean genotypes could have contributed to the bean yield reduction when intercropped with maize. The longer-flowering bean varieties were more affected by intercropping than were the shortest-flowering bean varieties. The potential benefit of introducing a short flowering bean variety associated with maize had an important increase in bean yield in associated intercropping compared with the sole cropping. This is translated into an increase in bean equivalent yield. However, there is no strong evidence of the potential applicability of sole crop bean flowering performance as an indicator of intercrop bean yield, and further research would be needed to test the hypothesis that both sole crop yield potential and relative bean yield reduction when intercropped may be predicted by flowering cycle duration.

Greater yield efficiency and higher net income in some intercropping patterns than in sole cropping suggest that the small farmer with limited resources is making a rational decision in maintaining his own complex system. Within this context, it would be necessary to improve these systems, minimizing cost, crop change and risk. Bush bean genotypes suffered lower reduction in yield when intercropped with sweet maize than when intercropped with field maize. Sweet maize was less competitive (flowering and yield) with simultaneously planted bush beans compared to intercropping with field maize. Greatest economic returns realized from dry beans intercropped with

Table 7
Simple correlations and Spearman's coefficient of rank correlations of common bean yields across cropping systems

Comparison	*r*-values between cropping systems							
	Trial 1		Trial 2		Trial 3		Trial 4	
	Flowering	Rank	Flowering	Rank	Flowering	Rank	Flowering	Rank
Sole crop vs Field intercrop	0.02	−0.01	−0.06	−0.02	−0.59**	−0.46*	0.18	0.34
Sole crop vs Sweet intercrop	−0.01	−0.23	0.19	0.18	−0.20	−0.13	0.33	0.40
Field intercrop vs Sweet intercrop	−0.26	−0.09	0.09	0.06	0.65**	0.64**	0.40	0.29

Trial 1, Pontevedra-1994. Trial 2, Mabegondo-1994. Trial 3, Pontevedra-1995. Trial 4, Mabegondo-1995. * Significant at $P<0.05$; ** Significant at $P<0.01$.

Table 8
Land equivalent ratio values (LERs) of bean and field maize intercrops and of bean and sweet maize intercrops and gross and net incomes from bean sole cropping and bean and maize intercropping systems

	Bean–field maize intercrop			Bean–sweet maize intercrop			Gross income (∈/ha)			Net income (∈/ha)		
Variety	Bean	Maize	Both	Bean	Maize	Both	Bean	Bean + field maize	Bean + sweet maize	Bean	Bean + field maize	Bean + sweet maize
PHA-0009	0.42	0.77	1.18	1.01	0.35	1.36	3311	2721	6115	1869	947	4341
PHA-0012	1.73	0.75	2.47	0.95	0.37	1.32	2553	5713	5363	1111	3939	3589
PHA-0013	0.25	0.71	0.97	0.72	0.40	1.12	5314	2599	7053	3872	825	5279
PHA-0014	0.23	0.61	0.83	0.33	0.33	0.66	5951	2408	4573	4509	634	2799
PHA-0016	0.82	0.68	1.50	0.48	0.35	0.83	3284	3873	4359	1842	2099	2585
PHA-0041	0.61	0.64	1.26	0.70	0.31	1.01	2901	2904	4520	1459	1130	2746
PHA-0057	1.03	0.64	1.66	1.71	0.55	2.26	3176	4371	9844	1734	2597	8070
PHA-0065	0.26	0.64	0.89	0.16	0.35	0.51	7195	2948	3937	5753	1174	2163
PHA-0104	0.32	0.60	0.93	0.36	0.39	0.75	9917	4278	6685	8475	2504	4911
PHA-0471	0.53	0.66	1.19	0.59	0.35	0.93	4350	3472	5330	2908	1698	3556
Mean	0.45	0.67	1.12	0.56	0.37	0.93	5206	3529	5871	3764	1755	4097

Gross income based on large-medium dry bean price of 2.40 ∈/kg, field maize price of 0.18 ∈/kg and sweet maize price of 4.09 ∈/kg. Net income based on production cost: bush beans = 1442 ∈/ha and maize and beans = 1774 ∈/ha.

sweet maize. This change in the traditional cropping system (field maize–bean intercrop) would be not difficult to achieve in practice and could be an interesting alternative cropping system for small farmers along southern Europe under the pressure of an extensive agriculture. Moreover, when research technology for intercrops is as well developed as it is today for sole crops, and with the introduction of dry bean varieties which developed a good performance in intercropping, intercropping system will no longer be just for the farmer. Fresh, canned, and frozen sweet maize rank among the top vegetables in value and per capita consumption, and joined with the largest prices and the current interest for the consumers in medium-large dry beans, provided a cropping system with a high economical potential.

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References

Adams, M.W., 1967. Basis of yield compensation in crop plants with special reference to the field bean, *Phaseolus vulgaris*. Crop Sci. 7, 505–510.

Adams, M.W., Bedford, C.L., 1973. Breeding food for improved processing and consumers acceptance properties. In: Milner, N. (Ed.), Nutritional Improvement of Food Legumes by Breeding. Proceedings. United Nations Protein Advisory Group, New York, pp. 299–304.

Atuahene-Amankwa, G., Michaels, T.E., 1997. Genetic variances, heritabilities and genetic correlations of grain yield, harvest index and yield components for common bean (*Phaseolus vulgaris* L.) in sole crop and in maize × bean intercrop. Can. J. Plant Sci. 77, 537–538.

Baudoin, J.P., Camarena, F., Lobo, M., 1997. Improving *Phaseolus* genotypes for multiple cropping systems. Euphytica 96, 115–123.

Clark, E.A., Francis, C.A., 1985. Bean-maize intercrops: a comparison of bush and climbing bean growth habits. Field Crops Res. 10, 151–166.

Davis, J.H.C., Garcia, S., 1983. Competitive ability and growth habit of indeterminate beans and maize for intercropping. Field Crops Res. 6, 59–75.

Escribano, M.R., Santalla, M., Ron de, A.M., 1997. Genetic diversity in pod and seed quality traits of common bean populations from northwestern Spain. Euphytica 93, 71–81.

FAO, 1997. Production. Yearbook. Vol. 51.

Francis, C.A., Sanders, J.H., 1978. Economic analyses of bean and maize systems: monoculture versus associated cropping. Field Crops Res. 1, 319–335.

Francis, C.A., Prager, M., Laing, D.R., Flor, C.A., 1978. Genotype × environment interactions in bush bean cultivars in monoculture and associated with maize. Crop Sci. 18, 237–241.

Gomez, K.A., Gomez, A.A., 1984. Statistical Procedures for Agricultural Research, 2nd edn. Wiley, New York.

MAPA, 1999. Anuario de Estadística Agraria. Ministerio de Agricultura, Pesca y Alimentación, Spain.

Mead, R., Willey, R.W., 1980. The concept of a 'land equivalent ratio' and advantages in yields from intercropping. Exp. Agric. 16, 217–228.

Moreno, M.T., Martinez, A., Cubero, J.I., 1985. Bean production in Spain. In: Potential for Field Beans (*Phaseolus vulgaris* L.) in West Asia and North Africa. The Ford Foundation, CIAT and ICARDA, pp. 70–85.

Ron de, A.M., Santalla, M., Barcala, N., Rodiño, A.P., Casquero, P.A., Menendez, M.C., 1997. *Phaseolus* spp. at the Mision Biologica de Galicia, Spain. Plant Genet. Res. News 112, 100.

Rudzik, L.H., 1990. Applications of infra-red spectroscopy methods. In: Rapid Methods for Analysis of Food and Food Raw Material. Werner Baltes (Ed.), Hamburg, pp. 249–264.

Santalla, M., Ron de, A.M., Escribano, M.R., 1994. Effect of intercropping bush bean populations with maize on agronomic traits and their implications for selection. Field Crops Res. 36, 185–189.

Santalla, M., Ron de, A.M., Casquero, P.A., 1995. Nutritional and culinary quality of bush bean populations intercropped with maize. Euphytica 84, 57–65.

SAS Institute Inc., 1990. SAS/STAT User's Guide, Version 6, 4th ed., Vols. 1 and 2. SAS Institute Inc., Cary, NC.

TR-02, 1999. Improvement of sustainable *Phaseolus* production in Europe for human consumption. Phaselieu Concerted Action. FAIR5-PL97-3463. 7 pp.

Vandermeer, J., 1989. The Ecology of Intercropping. Cambridge University Press, Cambridge 237 pp.

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

Willey, R.W., Osiru, D.S.O., 1972. Studies on mixtures of maize and beans (*Phaseolus vulgaris* L.) with particular reference to plant population. J. Agric. Sci. Camb. 79, 517–529.

Williams, P.C., Stevenson, S.G., Starkey, P.M., Hawtin, G.C., 1978. The application of Near Infrared Reflectance Spectroscopy to protein-testing in pulse breeding programmes. J. Sci. Food. Agric. 29, 285–292.

Zimmermann, M.J.O., 1996. Breeding for yield in mixtures of common bean (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.). Euphytica 92, 129–134.