Working Document No. 47

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Editor: S. Beebe

BREEDING COMMON BEAN (*Phaseolus vulgaris* L.) FOR YIELD IN INTERCROP

María José de Oliveira Zimmermann*

Summary

Despite the growing industrialization, increasing modernization and technological sophistication of agriculture, and despite the fact that research has always been biased towards solecropping, intercropping will always represent a good proportion of bean production, especially in tropical areas, due to economical, technical and social reasons.

Among bean researchers, breeders have always been questioned on their work, because most breeding has been done in sole crop.

The present paper discusses some results from the literature on intercropping, addressed to answer the questions that are usually presented to breeders, with the following conclusions: 1 - Germplasm developed for sole crop may be good for intercropping, but this is not always true. 2 - The characteristics of bean plants that would be specifically adapted to intercropping are unknown, but disease resistance is important in all systems. 3 - Due to some conflicting objectives, special breeding programs for intercropping may not be a good option generally. 4 - A better approach might be a combined selection scheme, where early generation selection is made in sole crop, with testing of the best lines of each species as intercrops in all combinations of superior lines of the species,

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* Bean Breeder, Centro Nacional de Pesquisa de Arroz e Feijao (CNPAF), Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA). Rod. GYN 12, Km. 10, Caixa Postal 179, 74000 Goiania, Goiás, Brasil.

with cultivar release decisions being made on the basis of average yields of all systems tested.

Introduction

Common bean (Phaseolus vulgaris L.) is an autogamous annual legume, often grown in intercrop with other plant species, particularly where subsistence farming is practiced (Wiley and Osiru, 1972). The species that are intercropped, the spacial arrangement and relative density among them, may vary with location and farmers. Beans are most commonly intercropped with maize, but are also found with coffee, sorghum, cassava, sugar cane and other crops.

Intercropping is understood as the growing of two or more crops simultaneously in the same field, where crop competition occurs during all or part of crop growth (Andrews and Kassam, 1976). The more general term "multiple cropping" refers to all systems that include the growing of two or more crops in the same field in a year.

There are not reliable statistics on how much of the bean area is in intercropping in any country, but it is estimated that about 70% of bean production in Latin America comes from intercroping and that the companion species is usually maize (Pinchinat et al., 1976).

With the increasing industrialization in the countries of the developing world, agricultural labor has been decreasing and agricultural practices are changing in order to increase the efficiency of agriculture as a whole. As a consequence, areas devoted to intercropping will tend to decrease. This system is one of intensive land and labour use. It is projected that the decrease will continue until an "equilibrium point" is reached. Although such a point is as yet unknown, in tropical areas intercropping will probably always be important for the production of common bean.

There are many reasons why this is so. Some of them are:

a) Intercropping is a very efficient soil preservation practice due to the exploitation of different soil layers by the different depths occupied by the root systems of the two or more crop species.

b) Where sun-light is not a limiting factor, temperature is high and water availability not always ideal, a taller crop such as maize or sorghum, can reduce the intensity of heat and water stress for a shorther crop such as beans, by the shading due to the taller crop and also by a wind breaking effect. Such effect may reduce transpiration losses of water for the shorter crop.

c) Intercropping is a safer and more stable system of agricultural exploitation than sole cropping, for small areas with low input and labor availability. If one crop fails, the other can still give some yield (Andrews, 1974, Willey and Osiru, 1972).

d) Intercropping makes possible the production of two or more crops at the same time and area which favors diversification of diets.

Although it is accepted that intercropping is important for common bean production in all countries where beans are an important agricultural product, research has always been centered on sole cropping and germplasm development has always been done in that system. Few attempts were made to select cultivars for intercrop (Francis et al., 1976) and in most cases they were on climbing bean-maize associations, that have obvious advantages because maize provides the necessary support for the bean plants, that should otherwise be provided by stakes (Davis et al., 1980). However, most farmers who grow beans with maize, prefer bushy plant types because they make harvesting easier.

For many years, plant breeders have been questioned about their work in relation to intercropping. The main questions are:

I - Will germplasm that was developed for sole crop, necessarily be good for intercropping?

II - How will germplasm that was selected for sole crop differ from germplasm developed for intercropping?

III - Is there a need for special breeding programs for intercropping?

IV - How could bean breeding programs approach the intercropping question?

I. Will Germplasm That Was Developed For Sole Crop Be Always Good For Intercrop?

Several articles report yields of bean cultivars in sole crop and in intercropping with maize. In most cases the correlation coefficients between yields in sole crop and in intercrop were positive, high and significant (Table 1). These positive correlations have led to the conclusion that cultivars that are good for sole crop may also be good for intercrop. However, significant genotype by cropping systems interactions have been reported (Francis et al., 1978a). Paniagua (1977) found that not all bean cultivars which where good in intercrop where also good in sole crop.

Hamblin and Zimmermann (1986) showed that it is possible to calculate how succesful selection in one system (sole crop or intercrop) would be for the other, by ranking the cultivars for yield in each system, applying a defined selection pressure (in their case 33%) in one system and observing how many of the selected genotypes were among the top 33% in the other environment. Selection efficiency (Se) in the alternate environment is defined as:

$$Se\% = \frac{\text{no. selected in alternate system} - \text{no. expected by chance}}{\text{no. chosen in selection system} - \text{no. expected by chance}} \times 100$$

The number expected by chance, is calculated assuming that there would be the same probability of randomly taking good genotypes for the alternate system among the selected ones, as the selection intensity. For example: the trial of Santa- Cecilia and Ramalho (1982) included 40 genotypes. With a selection pressure of 30% in sole crop, the 12 best genotypes were identified for that system. Following the rationale described, the probability of having taking the best ones by chance, was 0,30 x 12 = 3. Among the 12 that were selected for sole crop, there were 7 that were in the group of the top 12 in intercrop. The number expected by chance was again the same (3), because it was again calculated from the top 12. So selection efficiency in that case was:

$$Se\ \% = \frac{7 - 3}{12 - 3} \times 100 = 44\%$$

That means that only 44% of the genotypes that were consciously selected in one system were also consciously selected for the other system, although the percentage of selected material in one system that was good for the other (correlated response) was 58%. Those are low percentages considering that there was a highly significant correlation for bean yields between the two planting systems.

Table 2, taken from Hamblin and Zimmermann (1986), shows the selection efficiency for intercrop when a selection intensity of 33% was applied in sole crop. In only two cases, selection efficiency was greater than 50%, but this result may be due to the differential disease resistance of the cultivars. In the case of Vieira and Aidar (1984), yield data and anthracnose data in sole crop and in intercrop were correlated. Also, disease incidence data in sole crop were correlated to the same data in intercrop, and the levels of resistance to anthracnose for each genotype were similar across systems.

The results are very similar, in general terms, for relay cropping (beans planted between maize lines when maize reaches physiological maturity) and for simultaneous intercropping. Although crop competition is reduced in relay cropping, because maize plants are not actively growing when beans are planted, correlations between yields in relay crop and sole crop are positive and low, and selection efficiency accross systems was even lower than simultaneous intercrop (Table 3).

In conclusion, germplasm that was developed for sole crop will not always be good for intercrop, although performance in the two systems is often correlated. Selection for disease resistance may be practiced in the most convenient system for disease expression, but yield has to be measured in the same system that the germplasm is to be grown.

II. How Will Germplasm That Was Selected For Sole Crop Differ From Germplasm Developed For Intercrop?

Selection parameters in common bean vary with the program and region for which they are being selected. Generally for sole crop, beans are selected for resistance to the prevailing diseases and to some environmental stresses. Those resistances are useful in all planting systems and are considered of equal importance for intercrop and sole crop. It is the morphophysiological traits that will more often determine adaptation to intercropping. Some traits may be more important to one system than to the other, and generally some traits appear to be of particular importance when selecting for adaptation to intercropping but they are not really understood.

Zimmermann et al. (1984b) studied the relative importance of some traits in segregating populations in intercrop and in sole crop. It was reported that the same interactions noted for varieties also occurred in segregating populations. In those studies of segregating populations, harvest index of beans was negatively related to yield in sole crop and positively in intercrop and such correlations are not only phenotypic but also genotypic (Table 4). For all other traits studied the genotypic correlations with grain yield were in the same direction for both systems, although for the phenotypic correlations there were some changes of sign. Those correlations show that it is important, when selecting for yield in intercrop, to avoid a correlated reduction in harvest index in order not to obtain plants with excessive vegetative growth (Donald and Hamblin, 1976 and 1983).

A path coefficient analysis for yield components and grain yield of beans (Zimmermann et al., 1984b) showed that the importance of such components for grain yield varied with system (Table 5), with the direct effect of 100 seed weight being more important for intercrop than for sole crop and the direct effect of number of pods per plant being the opposite. Also, for grain yield of F2 derived F4 and F5 progenies, the genotypic correlations between cropping systems (Zimmermann et al., 1984a) were higher for the cross when Dark Red Kidney 2602, a larger seeded, determinate cultivar was one of the parents, than for the other crosses where both parents were small seeded and indeterminate (Table 6).

Larger seed size gives plants a competitive advantage because they have more reserves at the begining of the life cycle (Black, 1958; Donald, 1963). In highly competitive situations, Hamblin (1975) also found that seed size was positively related to competitive ability measured as grain yield. These highly competitive situations involved different cultivars from the same species (<u>Phaseolus vulgaris</u> L.). It appears that the same relationship of seed size x competitive ability exists when competition is imposed by another species (such as maize), as Zimmermann shows.

Guazzelli (1975) evaluated bean lines for their competitive ability in mixtures, and even among black, small seeded, indeterminate bean lines, differences could be detected. In a complementary work, the same author (1976), applied selection for high and low competitive ability in four bean varieties (populations), and obtained lines that differed from the others for their competitive ability. Later, those lines were tested in intercrop situations (Vieira and Aidar, 1984; Guazzelli and Kluthcouski, 1988), and some of the ones that gave the best results for intercrop where those that had been selected for high competitive ability in common bean mixtures, which is technically a sole crop because it involves only one species.

The advantage of a more competitive bean cultivar in intercrop, suggests that the environment is not fully exploited by the current cultivars, which means that short term gains may be expected by the enhancement of competitive ability of beans. In medium and long term this may not hold because beans are grown for their seed production (reproductive growth) and competitive ability is related to vegetative growth (Donald and Hamblin, 1983). Donald and Hamblin (1983) suggest that some features common to high yielding lines, adapted to sole crop, make plants poor competitors but the crop fully exploits the environment. Those features are:

. Ability to respond to high densities
. Lodging resistance
. Annual habit and determinant growth
. Improved canopy for efficient light interception
. High biological yield
. High grain yield
. Minimum competitive ability between plants
. Ability to respond to high nutrient levels
. Wide climatic adaptation

Some of those features may not prove as good as the others for beans, or very hard to combine, but generally they may prove valuable. Davis and Garcia (1983) also suggested that indeterminate bean cultivars with low competitive ability may also have an advantage for intercropping.

Therefore the answer to "how will germplasm selected for sole crop differ from that developed for intercrop" is still unclear. Since there is not a clearly defined ideotype for either situation, it is unknown for which caracters the cultivars should differ from one another. There are only some indications of traits to pay attention to, in order to avoid some undesirable side effects of selection (like decreased harvest index, or increased seed size when small seeds are preferred).

III. Is There A Need For Special Breeding Programs For Intercropping?

This question was addressed in Zimmermann's work (Zimmermann, 1983; Zimmermann et al., 1984a; Zimmermann et al., 1984b; Zimmermann et al., 1985) through studies of genetic effects, heritabilities, correlations and selection gains for beans under sole crop and intercrop with maize under constant conditions. A greater number of significant genetic effects (Zimmermann et al., 1985) was found for grain yield and harvest index of beans grown in intercrop with maize than as sole crop (Table 7). Hamblin and Evans (1976) had also found that epistatic effects decreased with increased sowing density.

Zimmermann et al. (1984a), reported standard unit heritabilities (Table 8) that were larger for grain yield of beans in intercrop than in sole crop. In the same paper (Table 9) it was shown that direct selection for each system was more efficient than indirect selection. Effects of indirect selection for intercrop based on selection practiced in sole crop were much smaller than either effects of direct selection or effects of selection on the mean of both systems. Effects of indirect selection for sole crop based on selection in intercrop, were variable and sometimes larger than effects of direct selection, but selection based on the mean of both systems gave almost the same results and sometimes better results than direct selection for sole crop. These data showed that even if selection for intercrop only is not justified, selection based on the mean of both systems may improve the selection efficiency. Similarly, Hamblin and Zimmermann (1986) also found that selection on mean yield of sole crop and intercrop was always more efficient for both planting systems than selection in single environment for the alternate system (Table 10), and the mean was a better selection criterion to improve yield for both systems than "tolerance to stress", defined as the difference between yield in sole crop and in intercrop. These authors concluded that bad lines can be eliminated based on performance in a single system (for example sole crop) but the final identification of the best lines has to be made including all environments to which they should be adapted. Bean and maize, or any other species intercropped with beans, are grown in many geographical regions in more than one cropping system, and recommended lines should perform well across all or most of the different conditions in which they are grown. There are also doubts, whether or not a specially developed cultivar, for intercropping conditions would be the best approach for a seed production program that has to follow the breeding of a new cultivar.

A conclusion from the foregoing discussion is that special breeding programs for intercrop would not be justifiable unless intercropping is virtually the only planting system in which the crops are grown.

IV. How Could Bean Breeding Programs Approach The Intercropping Question?

The previous discussion considered beans as the system component of interest. From another point of view, in the bean-maize intercrop, maize yields are usually not affected or suffer very little from competiton from the bean plant, whereas bean may suffer a severe yield decrease of 80% or more. Furthermore, there are interactions of maize and bean cultivars in terms of bean yields, when different maize cultivars are used (Davis and Garcia, 1983; Ramalho et al., 1983). Harper (1967) and Fyfe and Rogers (1965) had previously suggested that if two species are to be grown together, the greatest level of ecological combining ability will be achieved by breeding both crops simultaneously. Hamblin et al. (1976), had suggested a method that allows it to be done, based on a diallel design. Hamblin and Zimmermann (1986) concluded that to obtain maximum crop yields in intercrop, plant breeders must breed for the cropping system rather than breed individual components.

Geraldi (1983) used a diallel approach with maize and bean lines in combination, each one of them with all others. The resulting yields of each crop were converted in "equivalent production" based on market price ratios of maize to bean, and analysed the data as an adaptation of Gardner and Eberhart (1966) model for diallel crosses. The best maize/bean combinations were those where there were large general effects of intercropping. In the case of bean cultivars, the best were those that interfered less with maize (high "combining ability"). Some exceptions of high specific "combining" ability also occurred. The only problem with this and other diallel methodologies is the size of experiments needed to test all combinations of the lines of the two species. For 10 bean and 10 maize lines, with 10 being a very small number of lines to be considered in any breeding program, a trial of 100 treatments is needed. For slightly larger, but still small numbers, the experimental size becomes too large to be handled efficiently.

A more reasonable approach would be, for all species involved, to work on early generation selection (screening phase) of a large number of lines, in the most simplified system (sole crop), with later testing of a much smaller number of entries of the different species in all systems that they should be grown in the region, in all possible combinations with the best lines of the other species. It increases the work only in the final phases of the program. The final decision on which line to name and release for each species should be made based on the average yield of lines across all testing environments. To make rapid yield gains on intercrop, selection in the early stages (sole crop) could be practiced under high planting density, as used by Guazzelli (1976).

From programs like the one suggested above, it would be possible to create and identify genotypes that would perform better in the average of a range of different cropping systems, but in some cases, they could perform not as well in each one of them alone as if they were specially developed for that from the begining, though the difference may not be as large as to be taken into account.

Conclusions

As final remarks, it is important to point out the following:

- Bean germplasm developed for sole crop may also be good for intercrop or for relay crop, but that is not always true. Interactions exist and have to be considered.
- There is no clear answer on how different or how similar bean lines developed especially for intercrop or for relay crop should be. There is no defined ideotype for those systems. Competitive ability seem to give an immediate yield advantage to genotypes grown in intercrop but selection to increase competitive ability may cause unwanted side effects that can decrease plant efficiency for seed production. Disease resistance, on the other hand, is important for all cropping systems.
- Special breeding programs, totally devoted to intercrop are not a good option unless intercropping is the only planting system in which crops are grown in a region.
- For all species that are grown in an intercrop situation with beans, early generation selection should be made in the cropping system which is most easily managed (sole crop) with final testing of the best

selected lines of each species being made in all systems and in all combinations among them. Final decisions on the releases to be made should be based upon averages across all testing systems.

Last, but not least, intercropping will probably decrease in importance throughout the world with time, but in the near future (until the end of century at least), it is from this system that a large proportion of bean production will come. As long as no good harvesting machines for beans are developed, as long as poor farmers exist, with small areas and no expensive and sophisticated production systems, without irrigation facilities, intercrop will continue to be responsible for a significant proportion of bean production.

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Table 1. Correlation between yields of bean cultivars in sole crop and in intercrop with maize (Adapted from Hamblin and Zimmermann, 1986).

No. of cultivars	r	Reference	Comments	
19	0.88**	Francis et al., 1978a	Trial 2	
20	0.51*	Francis et al., 1978a	Trial 3	
17	0.72***	Francis et al., 1978a	Trial 2	common
17	0.55*	Francis et al., 1978a	Trial 3	cultivars
20	0.81***	Francis et al., 1978b	Trial 2	
20	0.41 n.s.	Francis et al., 1978b	Trial 3	
18	0.83***	Francis et al., 1978b	Trial 2	common
18	0.54*	Francis et al., 1978b	Trial 3	cultivars
59	0.66***	Antunes and Teixeira, 1982	Trial 1	
64	0.54***	Antunes and Teixeira, 1982	Trial 2	
34	0.69***	Antunes and Teixeira, 1982	Trial 1	common
34	0.50***	Antunes and Teixeira, 1982	Trial 2	cultivars
49	0.84***	Vieira and Aidar, 1984		
40	0.65***	Santa-Cecilia and Ramalho, 1982	Year1	common
40	0.89***	Santa-Cecilia and Ramalho, 1982	Year2	cultivars
8	0.28 n.s.	Chagas and Aquino, 1981		
10	0.61 n.s.	Davis and Garcia, 1983	Short maize	
10	0.24 n.s.	Davis and Garcia, 1983	Medium maize	
10	0.41 n.s.	Davis and Garcia, 1983	Tall maize	
9	0.43 n.s.	Serpa and Barreto, 1982	Site 1	common
9	0.91***	Serpa and Barreto, 1982	Site 2	cultivars
40	0.64***	Ramalho et al., 1983		
8	0.89***	Araujo, R.S. (personal commun.)	Applied N	
8	0.43 n.s.	Araujo, R.S. (personal commun.)	Rhizobial N	

*, **, *** = significant at the probability levels of 5%, 1% and 0.1%, respectively.
n.s. = non significant.

Table 2. Effect of selection of the highest yielding 33% of cultivars in one environment on the number selected in the alternate environment, and selection efficiency (Adapted from Hamblin and Zimmermann, 1986).

No. cult.	No. sel.	No. alt. env.	No. exp. chance	Sel eff. %	Corr.	Reference
19	6	4	2	50	0.88***	Francis et al., 1978a
20	6	2	2	0	0.51*	Francis et al., 1978a
20	6	3	2	25	0.81***	Francis et al., 1978b
20	6	1	2	25	0.41 n.s.	Francis et al., 1978b
59	20	13	7	46	0.66***	Antunes and Teixeira, 1982
64	21	13	7	43	0.54***	Antunes and Teixeira, 1982
49	16	14	5	82	0.84***	Vieira and Aidar, 1984
40	13	7	4	33	0.65***	Santa-Cecilia and Ramalho, 1982
40	13	11	4	78	0.98***	Santa-Cecilia and Ramalho, 1982
40	13	5	4	11	0.64***	Ramalho et al., 1983

*, *** = Significant at the probability levels of 5% and 1%, respectively.

n.s. = non significant.

Table 3. Correlations between sole crop and intercrop or relay crop (Adapted from Hamblin and Zimmermann, 1986).

Data source	Corr. coef.	Comments	
Francis et al., 1978a	0.72***	Sole crop x simultaneous intercrop,	trial 2
Francis et al., 1978a	0.55*	Sole crop x simultaneous intercrop,	trial 3
Francis et al., 1978b	0.83***	Sole crop x simultaneous intercrop,	trial 2
Francis et al., 1978b	0.54*	Sole crop x simultaneous intercrop,	trial 3
Antunes and Teixeira, 1982	0.69***	Sole crop x simultaneous intercrop,	trial 1
Antunes and Teixeira, 1982	0.50**	Sole crop x simultaneous intercrop,	trial 2
Santa-Cecilia and Ramalho, 1982	0.65***	Sole crop x simultaneous intercrop,	year 1
Santa-Cecilia and Ramalho, 1982	0.89***	Sole crop x simultaneous intercrop,	year 2
Teixeira Monteiro et al., 1981	0.71**	Sole crop x relay crop, location 1	
Teixeira Monteiro et al., 1981	0.29	Sole crop x relay crop, location 2	
Antunes and Teixeira, 1982	0.33**	Sole crop x relay crop, year 1	
Antunes and Teixeira, 1982	0.46***	Sole crop x relay crop, year 2	

*, **, *** = Significant at the probability levels of 5%, 1% and 0.1%, respectively.
n.s. = non significant.

Table 4. Phenotypic and genotypic correlations among four traits of common bean and grain yield in intercrop and in sole crop (Adapted from Zimmermann et al., 1984b).

Trait correlated to grain yield	Genotypic correlation		Phenotypic correlation	
	Intercrop	Sole crop	Intercrop	Sole crop
Number of pods	3.58	1.30	-0.34**	0.42 n.s.
Seeds per pod	-0.95	-0.14	-0.21 n.s.	0.05 n.s.
100 seed weight	1.39	0.20	0.68**	0.06 n.s.
Harvest index	1.80	-0.20	0.77**	-0.11 n.s.

*, ** = Significant at the probability levels of 5% and 1%, respectively.
n.s. = non significant.

Table 5. Path coefficient analysis of the effects on grain yield of yield components of beans grown in intercrop with maize and in sole crop (Adapted from Zimmermann et al., 1984b).

Type of effect	Intercrop	Sole crop
Effect of total number of pods		
Direct effect	0.451	1.115
Indirect effect via seeds/pod	0.399	0.307
Indirect effect via 100 seed weight	-1.190	1.002
Total correlation	-0.34**	0.42
Effect of number of seeds per pod		
Direct effect	0.782	0.472
Indirect effect via number of pods	0.230	0.724
Indirect effect via 100 seed weight	-1.222	-1.146
Total correlation	-0.21 n.s.	0.05 n.s.
Effect of 100 seed weight		
Direct effect	1.608	1.318
Indirect effect via number of pods	-0.334	-0.847
Indirect effect via seeds per pod	-0.594	-0.411
Total correlation	0.68**	0.06 n.s.

*, ** = Significant at the probability level of 1%.
n.s. = non significant.

Table 6. Genotypic correlations between the two cropping systems for F2 derived F4 and F5 progenies from three crosses (Adapted from Zimmermann et al., 1984a).

Crosses	Correlations
Dark Red Kidney 2602 x Turtle Soup 39	1,08
California Small White 7775 x Turtle Soup 39	0,41
Gloria x Turtle Soup 39	0,25
All lines	0,99

Table 7. Models that fit the observed data for grain yields and harvest index of three common bean crosses. The genetic parameters that were included in the models showed estimated values larger than two times the estimates of their standard errors (Adapted from Zimmermann et al., 1985).

Crosses	Models: Grain yield, Intercrop	Grain yield, Sole crop	Harvest index, Intercrop	Harvest index, Sole crop
Dark Red Kidney 2602 x Turtle Soup 39	m+a-d+dd	m+ad	m-d+dd	m+a+aa
California Small White 7775 x Turtle Soup 39	m-a+d	m+d+ad	m-a+d+ad-dd	m+d
Gloria x Turtle Soup 39	m+d	m-a+d+aa	m+a+d+aa	m+a

m = mid parental value; a = additive effect; d = dominance effect; aa = additive by additive epistasis; ad = additive by dominant epistasis; dd = dominant by dominant epistasis.

Table 8. Standard unit heritabilities % determined by correlations between grain yield of F_4 and F_5 bean lines for two cropping systems (Adapted from Zimmermann et al., 1984a).

Crosses	Heritabilities %: Intercrop	Heritabilities %: Sole crop
Dark Red Kidney 2602 x Turtle Soup 39	53	51
California Small White 7775 x Turtle Soup 39	36	40
Gloria x Turtle Soup 39	50	28
All lines	60	54

Table 9. Realized selection responses (kg/ha) to a 40% selection intensity for grain yield, expressed as deviations from the population mean (Adapted from Zimmermann et al., 1984a).

	Selection for intercrop			Selection for sole crop		
		Indirect selection			Indirect	
Crosses	Direct	In sole crop	On mean	Direct	In intercrop	On mean
Dark Red Kidney 2602 x Turtle Soup 39	78	29	45	53	67	49
California Small White 7775 x Turtle Soup 39	42	33	39	83	53	82
Gloria x Turtle Soup 39	53	12	52	43	-9	84
All lines	91	45	63	140	30	139

Table 10. Selection efficiency % of three selection criteria: mean yield (SC +M)/2, tolerance (SC-M) and single environment selection (S) for the alternate system (Adapted from Hamblin and Zimmermann, 1986).

Source	Selection criteria	Test environments		
		Sole crop	Intercrop	Alternate
Antunes and Teixeira (1982)				
Year 1. Simultaneous intercrop	(SC+M)/2	86	57	-
	(SC-M)	-57	-29	-
	S	-	-	43
Year 1. Relay crop	(SC+M)/2	57	29	-
	(SC-M)	-57	14	-
	S	-	-	14
Year 2. Simultaneous intercrop	(SC+M)/2	86	57	-
	(SC-M)	-29	0	-
	S	-	-	43
Year 2. Relay crop	(SC+M)/2	43	86	-
	(SC-M)	-43	14	-
	S	-	-	29
Santa-Cecilia and Ramalho (1982)				
Site 1. Simultaneous intercrop	(SC+M)/2	78	66	-
	(SC-M)	-22	33	-
	S	-	-	33
Site 2. Simultaneous intercrop	(SC+M)/2	89	89	-
	(SC-M)	-22	-22	-
	S	-	-	78