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CROPPING SYSTEM EVALUATION AND SELECTION OF COMMON BEAN GENOTYPES FOR A MAIZE/BEAN INTERCROP

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ABSTRACT

Genotype x cropping system interactions frequently occur in common bean (*Phaseolus vulgaris* L.) cultivars in intercrops with maize (*Zea mays* L.). The purpose of this study was to determine the cropping system suited for selecting bean cultivars for production in an intercropping system. Sixty-three genotypes of common bean were evaluated in sole and intercrops across three environments, for seed yield and other characters. Cropping system significantly affected yield, pods per plant and seeds per pod. Genotype x cropping system was significant for several traits, including yield. Heritability estimates were comparable between cropping systems for all traits except pods per plant and canopy width. For most traits, predicted direct response to selection for a trait in one cropping system was greater than predicted correlated response to selection in the other. Using a selection intensity of 25%, the majority of high yielding lines selected in sole crop also emerged high yielding in intercrop. Selection of bush bean cultivars intended for intercropping should initially be conducted under sole crop conditions.

Key Words: Genotype x cropping interaction, *Phaseolus vulgaris, Zea mays*

RÉSUMÉ

Les intéractions entre génotypes et systèmes de cultures apparaissent fréquemment dans la combinaison des variétés du haricot commun (*Phaseolus vulgaris* L.) et du maïs (*Zea mays* L.). L'objet de cette étude était de déterminer le système de cultures adéquat pour la sélection des variétés des haricots pour un système de production en interculture. Soixante trois génotypes du haricot commun étaient évalués en monoculture et interculture dans trois types d'environnements pour les rendements en graines et autres caractères. Le système de cultures affecta significativement le rendement, le nombre de gousses par plante et les graines par gousse. L'intéraction génotype-système de cultures était significative pour plusieurs traits y compris le rendement. Les estimation d'héritabilié étaient comparables entre systèmes des cultures pour tous les traits à l'exception du nombre de gousses par plantes et la largeur de la couverture végétale. Pour la plupart des traits, la réponse directe prédite à la sélection d'un trait dans un système de cultures était grande que la réponse corrélée prédite à la sélection dans un autre système. Utulisant une sélection d'intensité 25%, la majorité de races à rendement élévé sélectionnées en monoculture émergèrent à rendement élévé en interculture. La sélection des variétés sauvage de haricot pour l'interculture devra être testé initiallement dans les conditions de monoculture.

Mots Clés: Intéraction génotype-système de culture, *Phaseoulus vulgaris, Zea mays*

INTRODUCTION

Common bean is often intercropped with maize throughout the tropics (Singh, 1992). Studies have shown that when intercropped with maize, beans generally suffer more yield decline than the maize (Francis *et al.*, 1978a; Davis and Garcia, 1983; Clark and Francis, 1985), suggesting that bean yield is the critical and more sensitive factor to overall improvements of the intercrop productivity. Climbing bean (type V) cultivars have traditionally been intercropped with maize, but recently, bush beans (types I and II) have become popular due to their general suitability in both intercrop and sole crop. Bush beans are easy to harvest, they combine well with maize, and are less competitive with maize than climbing beans and so do not suffer high yield losses as found in climbing beans (Davis and Garcia, 1983; Clark and Francis, 1985; Singh, 1992). Generally, maize yield loss is low when intercropped with bush beans. In contrast, the more competitive climbing beans can cause serious stem lodging and yield reduction in the associated maize (Davis and Woolley, 1993).

Most often, the development of improved bean cultivars for intercropping is done using sole crop, but several investigations have shown significant interactions between cropping systems and common bean genotype (Francis *et al.*, 1978b, c; Zimmermann *et al.*, 1984b). Although genotype x environment interactions are important in bean breeding under sole crop conditions, the relative importance of genotype x environment interactions in both sole and intercrop systems has not been evaluated.

Heritability and genetic gains expected from selection of grain yield and other important agronomic traits in both sole crop and intercrop have not been studied extensively. In one of the few investigations that examined these parameters, Zimmermann *et al.* (1984a) compared the parental, F_2, F_4 and backcross generations of three common bean crosses in sole and intercrops. They found that the heritabilities for four of five traits studied, including yield, were slightly higher in sole crop than in intercrop. However, in a related investigation, Zimmermann *et al.* (1984b) reported that two of the three crosses studied had higher heritabilities for bean yield in the intercrop than in the sole crop. The authors showed that the genetic gain from direct selection of bean yield in intercrop was generally greater than such gain from direct selection in sole crop or indirect selection in sole crop for intercrop.

The objective of this study was to estimate the heritability and response to selection for seven agronomic traits of common bean in sole and intercrops, and to compare the extent of genotype x environment interaction effects for the traits in both cropping systems. Such information would be useful in determining which cropping system is better suited for selecting bean genotypes intended for intercrop with maize.

MATERIALS AND METHODS

Sixty-three genotypes, consisting of 60 F_5-derived lines and three cultivars (OAC Sprint, OAC Gryphon and OAC Laser), were evaluated in 1994 and 1995. The bean programme at the University of Guelph, Ontario, Canada developed this material. The 60 F_5 derived lines were developed from five crosses involving white seeded common bean cultivars and lines (Table 1), through a modified single seed descent (a single pod advanced instead of a single seed). In each of the five crosses originated twelve lines, the progenies of twelve individual F_5 plant selections. The 60 lines were evaluated in the first

TABLE 1. Crosses used to generate the lines for this study

Cross reference number	Parents
30	OAC Laser (Midnight/Seafarer) x W72988 (Unknown Belize selection)
04	OAC Gryphon (Ex Rico 23*6/Narda) x W55788 (Midnight/Ex Rico 23//Domino/ Neptune)
25	OAC Speedvale (Seafarer//PI324685) x W55788 (Midnight/Ex Rico 23//Domino/Neptune)
31	OAC Laser (Midnight/Seafarer) x W72188 (Kentwood/Seafarer Are)
18	OAC 88-2 (Midnight/Seafarer) X W55788 (Midnight/Ex Rico 23/Domino/Neptune)

year of the study and in second year, as $F_{5:7}$ and $F_{5:8}$ respectively, along with the three cultivars.

The lines consisted of determinate (type I) and indeterminate (type II) bush beans that had a two-week range in maturity. The lines and the three cultivars were a subset of material grown in a 9 x 9 lattice design, in sole crop and intercrop, for a broader study, in which eighty one genotypes of common beans were planted in each cropping system. The 60 F_5 derived lines and the three cultivars were common to both cropping systems.

In 1994, maize and beans were planted on June 2 with two replications at the Elora Research Station, Elora, Ontario (43^0 38' N, 80^0 24' W; elevation 376 m). The soil is a Guelph loam (classified as orthic grey brown luvisol). Single row plots of 5 m length were used in sole crop with inter-row spacing of 60 cm. In the intercrop, each 5 m row of common bean was planted between two rows of hybrid maize (Pioneer 3921), with a distance of 50 cm between the bean and maize rows. Maize rows were thinned to approximately five plants per meter for a plant density of 50,000 plants per hectare. Beans were over planted and thinned to 10 plants per meter in both cropping systems to provide a plant density of 100,000 per hectare in intercrop and 167,000 plants per hectare in sole crop.

A pre-plant application of 40 kg ha^{-1} P and 40 kg K ha^{-1} was applied. Ammonium nitrate fertiliser, at the rate of 30 kg N ha^{-1}, was side-dressed thirty days after planting. Inter-row mechanical cultivation and hand-weeding were used to control weeds.

In 1995, the trial was conducted at the Elora Research Station and the Woodstock Research Station (43^0.13' N, 80^0 46' W; elevation 282 m). The soil at Woodstock is a Guelph silt loam (grey brown podzolic). Maize and beans were planted on the same day at each location. The experiment was laid out in 9 x 9 lattice design with three replications at each location.

Bean yield was collected by harvesting all the plants in middle 4 m (1994) and 5 m (1995) of the bean rows. Grain yield was adjusted to 18% moisture. At maturity, ten plants selected randomly were collected from each plot to obtain data for pods per plant, seeds per pod and 100-seed weight. Days to physiological maturity were also recorded. Canopy width and height were recorded after pod formation only at the Elora site. The measurements were made at four random locations in the plots, from which plot means were determined.

Statistical analyses. Data obtained from each environment were initially analysed according to the lattice design using a locally written Advanced Programming Language (APL) program (Petar Gostovic, pers. commun.). Data for all traits were tested for homogeneity of error variances using Bartlett's test (Steel and Torrie, 1980). Thereafter, data involving the 63 genotypes were used to conduct combined analyses of variance over cropping systems and environments. Where the initial lattice analyses for trait showed greater than 110 percent efficiency of the lattice design over a randomised complete block design, adjusted plot values were generated for the combined analyses of variance (Federer, 1955), otherwise, the unadjusted plot values were used. The combined analyses were performed using the General Linear Models procedure (SAS Institute, 1988). The genotypes and environments were considered random factors, while cropping system was considered a fixed factor. Within each cropping system, a separate combined analysis was also conducted for each trait, and from these analyses, genetic components of variances and heritabilities were estimated for each trait using plot means. A comparison of means across cropping systems for each trait was done using protected least significant difference (LSD) values.

Broad-sense heritability was estimated on an entry mean as $h^2 = \sigma^2_G / (\sigma^2_G + \sigma^2_{GE}/e + \sigma^2_E/re)$, where h^2 represents heritability, σ^2_G is genotypic variance, σ^2_{GE} is genotype x environment variance, σ^2_E is error variance, r is number of replications and e is number of environments. A weighted value of 2.33 for number of replications, generated by PROC VARCOMP procedure of SAS (SAS Institute, 1988) was used. Response to selection was predicted after Falconer and Mackay (1996) as $R_x = ih^2\sigma_p$; where R_x represents expected selection response, i is standardised selection differential; h^2 is defined above, and σ_p = phenotypic standard deviation. A selection intensity of 25% was assumed (i = 0.8356 from Becker, 1984). Indirect response to selection in the alternative system was calculated for each cropping system as $CRy = \beta_{GyGx}R_x$ where CR_y is the correlated response in one system, β_{GyGx} is the regression coefficient between the genetic values of the two cropping systems, and R_x is defined above (Falconer and Mackay, 1996). The regression coefficients were calculated as $\beta_{GyGx} = r_g.\sigma_{Gy}/\sigma_{Gx}$, where r_g represents genetic correlation between cropping systems, σ_{Gx} = genetic variance in sole crop and σ_{Gy} = genetic variance in intercrop. Genetic correlations between sole crop and intercrop were calculated as: $r_g = \sigma_{Gxy} / \sigma_{Gx}\ \sigma_{Gy}$, where σ_{Gxy} is the genetic covariance between cropping systems, and σ_G and σ_{Gee} are defined above. Observed direct response to selection in each cropping system was calculated by selecting the top 25% of the genotypes at Elora in 1994 and estimating their response based on the average performance in 1995 at Elora and Woodstock. Similarly, observed indirect response to selection for a given cropping system based on selection in the alternative system was calculated by selecting the top 25% of the entries in a given system at Elora in 1994 and estimating their response in the alternative system in 1995 at both Elora and Woodstock.

RESULTS

Analyses of variance. Error variances were found to be homogenous for seeds per pod, canopy width and height, but heterogeneous for seed yield, pods per plant, 100-seed weight, and days to maturity (Table 2). With the exception of pods per plant, individual coefficients of variation for all traits were found to be less than 20%; hence, a combined analysis of variance was performed for all traits, as suggested by Gomez and Gomez (1984). There was significant genotypic variation for all traits in the combined analyses over environments (Table 2). Likewise, environmental variation was significant for all traits, except canopy width. Differences between sole crop and intercrop were significant for three traits: seed yield, pods per plant and seeds per pod. Genotype and cropping system interactions were significant for seed yield, pods per plant, 100 seed weight, canopy width and canopy height. Significant or highly significant effects of interactions were observed between cropping system and environment and between genotype and environment. The genotype x environment interaction was due to changes in both magnitude of variances and rank order of genotypes. However, for all traits, the sums of squares due to the main effects of cropping system, environment and genotype accounted for most of the total variation. For example, 68% of the total variation for grain yield in the combined analyses was attributable to main effects of the three factors.

Means, components of variances, and heritabilities. Yield averaged 73% higher across environment in sole crop than in intercrop (Table 3). Similarly, pods per plant averaged 92% higher in sole crop, and seeds per pod 11% higher. Means for the other traits were, however, not significantly different between cropping systems.

Genetic variances for all traits, with the exception of pods per plant, were significant in both cropping systems. Within the intercrop, genotype x environment variance component was significant for most traits except days to maturity, canopy width, and canopy height. The genotype x environment component accounted for a larger percentage of variability in intercrop for all traits, except seeds per pod and days to maturity (Table

TABLE 2. Mean squares for agronomic characters measured on 63 common bean genotypes evaluated in three environments in sole crop and intercrop

Source of variation	df+	Seed yield	Pods per plant	100-seed weight	Seeds per pod	Days to maturity	Canopy width	Canopy height
Environment (E)	2 (1)	16242766**	2413.8**	25.0**	109.1**	27887.9**	545.0	190.0**
Cropping system (CS)	1 (1)	162621748**	10566.5**	59.9	45.2**	905.2	8305.0	47.3
E x CS	2 (1)	4464349**	298.7**	28.4	0.7*	1333.4**	1392.0**	518.1**
Rep (E x CS)	8 (4)	851673**	40.0**	1.5**	0.6*	115.1**	652.0**	29.3
Genotypes (G)	62	689001**	40.0**	13.7**	1.8**	120.7**	80.8**	125.0**
G x E	124 (62)	147298**	19.6*	1.8**	0.5**	22.4**	31.1	18.0
G x CS	62	191340*	18.5*	1.6**	0.3	17.5	32.8*	21.1*
G x E x CS	124 (62)	131263**	12.3**	0.8	0.4**	16.4	21.0	13.5
Error	496 248)	94120	7.9	0.6	0.3	14.7	22.3	13.7

* ** significant at P<0.05 and 0.01, respectively; + df for canopy width and canopy height are in brackets

3). In particular, the influence of genotype x environment effects on both grain yield and pods per plant were substantially higher in intercrop than in sole crop. The error variances for these two traits were substantially higher in sole crop than in intercrop, reflecting a tendency for higher phenotypic variances in sole crop, while the other traits showed similar environmental variances across cropping system. As with genetic variances, the estimates of heritability differed only slightly between sole crop and intercrop, with the exceptions of pods per plant (higher in sole crop) and canopy width (higher in intercrop).

Response from selection. For all traits, except seeds per pod, the predicted response to direct selection was equal to, or better than, the correlated response from indirect selection (Table 4). This was seen in both cropping systems. Most traits showed a 10-30% advantage with direct selection over indirect selection, although values ranged from 0% for pods per plant in intercrop and maturity in the sole crop, to 200% for pods per plant in sole crop. Differences between observed direct and indirect response to selection were influenced by cropping system, particularly for grain yield and pods per plant (Table 4). In sole crop, direct selection was approximately twice as effective as indirect selection in increasing the mean response for seed yield, while in intercrop mean observed direct and indirect responses to selection for seed yield and pods per plant appear to be equal in intercrop

Table 5 shows that nine of the 16 highest yielding genotypes in sole crop were in the top 16 genotypes in intercrop, including five in the top 10. In sole crop, cross 30 and cross 04 showed four superior lines each, the highest number for any family. Cross 18 was the next one, with three lines, then cross 31 (two lines) and cross 25 (one line) followed in that order. Among these superior lines, all those identified in crosses 04 and 18 appeared in the top 16 in intercrop; two of the lines from cross 30 appeared the top 16 genotypes in intercrop, while none from crosses 31 and 25 appeared in the top 16 in intercrop.

TABLE 3. Means, relative contribution (%) by components of variances [genetic (σ^2_g), genotype x environment (σ^2_{ge}) and experimental error (σ^2_0)] and heritabilities (h^2) for common bean grown in sole crop (SC) and in maize/bean intercrop (IC)

Trait	Cropping system	Means	σ^2_g	σ^2_{ge}	σ^2_0	h^2
Seed yield (kg ha^{-1})	Sole crop	2124a	28**	7	65	0.70±0.18
	Intercrop	1229b	27**	23**	50	0.65±0.18
Pod plant^{-1}	Sole crop	14.6a	12**	26**	62	0.40±0.19
	Intercrop	7.6b	1	76**	23	0.14±0.20
100-seed weight (g)	Sole crop	18.1a	49**	14**	37	0.83±0.17
	Intercrop	18.5a	49**	18**	33	0.83±0.18
Seeds per pod	Sole crop	5.1a	15*	16**	69	0.52±0.18
	Intercrop	4.6b	22**	14**	64	0.61±0.18
Days to maturity	Sole crop	94.5a	25**	13**	62	0.65±0.18
	Intercrop	96.4a	34**	4	62	0.78±0.18
Canopy width (cm)	Sole crop	51.4a	12*	1	87	0.36±0.21
	Intercrop	59.5a	32**	11	57	0.62±0.18
Canopy height (cm)	Sole crop	52.7a	53**	0	47	0.82±0.18
	Intercrop	52.1a	47**	6	47	0.76±0.18

*, ** estimates of σ^2_g, or σ^2_{ge} significant at $P<0.05$ and 0.01, respectively; means of a given trait followed by the same letter are not significantly different

DISCUSSION

For reasons including time, cost, and availability of seed, breeders tend to make selections in earlier generations using a single environment and cropping system, and then conduct trials in multiple environments and cropping systems in subsequent generations. Therefore, it is important that the initial evaluation of breeding material retain lines that will perform well in the intended cropping system.

The presence of significant genotype x cropping system interactions, most often in the understory crop, has been reported in many review articles

TABLE 4. Predicted and observed responses to selection for agronomic traits of common bean grown in sole crop and in maize/bean intercrop

Trait	Cropping system	Predicted response		Mean observed response	
		Direct	Indirect	Direct	Indirect
Seed yield (kg ha^{-1})	Sole crop	249	202	133	79
	Intercrop	170	150	82	84
Pod plant^{-1}	Sole crop	1.2	0.4	1.0	-0.1
	Intercrop	0.2	0.2	0.4	0.7
100-seed weight (g)	Sole crop	1.1	0.9	0.6	0.6
	Intercrop	1.1	0.9	1.0	1.0
Seeds per pod	Sole crop	0.2	0.3	0.1	0.1
	Intercrop	0.3	0.4	0.2	0.1
Days to maturity	Sole crop	2.5	2.6	1.0	2.1
	Intercrop	3.1	2.8	1.5	1.1
Canopy width (cm)†	Sole crop	1.3	1.00	1.0	2.9
	Intercrop	3.0	2.0	10.0	7.1
Canopy height (cm)†	Sole crop	4.0	3.4	2.5	3.4
	Intercrop	4.3	3.9	2.4	-0.4

† response for trait was based on data collected at Elora only

TABLE 5. Mean yield and ranking of the top 16 of 63 genotypes in sole crop, and their relative performance in intercrop, in trials across three environments

Genotype	Sole crop		Intercrop	
	Seed yield (kg ha^{-1})	Rank	Seed yield (kg ha^{-1})	Rank
30-11	2669	1	1496	7
30-04	2609	2	1400	17
04-02	2575	3	1511	6
18-08	2560	4	1480	9
31-07	2545	5	1095	49
OAC Laser	2500	6	1289	32
04-01	2475	7	1408	14
18-03	2451	8	1636	2
18-01	2445	9	1445	12
04-09	2444	10	1665	1
04-11	2403	11	1471	11
31-11	2401	12	1308	27
OAC Gryphon	2361	13	1364	22
30-01	2356	14	1425	13
25-01	2348	15	903	58
30-07	2333	16	1284	33
LSD (0.05)	429.4		348.3	

about intercropping (Francis *et al.*, 1976; Francis 1985; Davis and Woolley, 1993). Considerable yield variability among climbing bean genotypes has been reported when intercropped with maize (Davis and Garcia, 1983). However, less significant interactions have been noted with bush bean cultivars (Francis *et al.*, 1982; Clark and Francis, 1985). Clark and Francis (1985) suggested that the longer growth phase of climbing beans, relative to bush beans, was inhibited to a greater degree by maize resulting in greater genotype x cropping system interactions. The results of the present study, using bush bean genotypes, show significant genotype x cropping system interactions for five of seven traits, including yield. The hypothesis of Clark and Francis (1985) explains equally well the interactions seen with bush bean genotypes used in this study, even if the interactions are to a lesser degree. Cropping system significantly influenced seed yield, pods per plant and seeds per pod (Table 2) with mean values of 73, 92 and 11% higher in sole crop (Table 3), respectively. Research by Adams (1982) on bean architecture and its relationship to yield has shown that higher yielding lines have an architecture better suited to light interception, particularly between flowering and maturity, which translates into higher yield. Although a thorough analysis of plant form was not conducted in this study, canopy width and canopy height were not affected by cropping system. These observations suggest that the plants in the intercrop had attained a canopy form suitable for seed production equivalent to that occurring in sole crop, but were unable to reach the same level of production because of competition for light and other resources during the critical growth period after flowering. A decrease in maturity cannot be attributed as the cause of decreased yield since maturity was unaffected by cropping system. (Tables 2 and 3).

Heritability estimates obtained for the seven traits were similar between cropping systems, except for pods per plant and canopy width (Table 3). This suggests that, for most traits, the progress from selection is likely to be similar between cropping systems. The heritability for seed yield was high and unexpected, and may in part be because the population studied consisted of lines that originated from different crosses. However, pre-selected lines are often used to estimate heritability values (Akhter and Sneller, 1996). Therefore, the heritability values reported here may be useful for comparing trait selection in sole crop and intercrop. These results are at variance with the findings of Rosielle and Hamblin (1981) that heritabilities are generally lower in stressed environment (i.e., intercrop situations), a situation that would discourage selection in intercrop. Zimmermann *et al.* (1984a, b) found similar heritability estimates between cropping systems when measured in early generations (F_2), but found higher heritability estimates in intercrop than in sole crop at later generations (F_4). The higher values of heritability for seed yield observed with the advanced stage of material used in this study (F_7/F_8) are consistent with the trend seen by Zimmermann *et al.* (1984b).

The high heritability estimates in combination with the increase in phenotypic and genetic variation, which occurs in a population with inbreeding, produced large values for the predicted response to selection (Table 4). However, the mean observed responses were generally lower for most traits in both cropping systems. This is likely the result of the significant effect of environment (Table 2), which could have decreased trait values in the second year trial.

In both cropping systems, direct selection was predicted to produce equivalent to or higher responses than indirect selection for all traits, except seeds per pod, which showed a slightly lower response. The mean observed responses to indirect selection (Table 4) for intercropping revealed similar gains in comparison with direct selection for most traits. With respect to yield, Zimmermann *et al.* (1984b) found direct selection for intercrop to be more effective than indirect selection. The similar mean responses to indirect and direct selection across environments for yield and pods per plant in intercrop could be the result of genotype x environment interactions observed (Table 3). While significant genotype x environment interactions were seen with other traits, the relative contribution of the interactions to total variance may not be large enough to alter trait values between environments substantially. Kelly *et al.* (1987) reported genotype and cropping system interactions in sole crop for yield in determinate bean cultivars. The results presented here differ from those of Rezende and Ramalho (1994), who found significant genotype x location interactions for grain yield of the maize or common bean only in monoculture.

The significant effects of both genotype x environment and genotype x cropping system interactions, as well as the other higher order interactions, are reflected by the absence of four of the top 16 genotypes in sole crop from the top 50% in intercrop, and two of those four were not even in the top 75% in intercrop (Table 5). The change in rank order of the lines indicates that a lower selection intensity (25% in this study) than normal may be required to allow for these changes in performance.

Selection of sole crop varieties for maximum performance in a specific growing environment is conducted by testing breeding material in that environment. However, this approach must be balanced by the increase in cost, time, and space required for intercropping. Davis *et al.* (1985) felt that such testing was justified if significant genotype x cropping interactions were present. In the present study, genotype x cropping system interaction was present but the main effects accounted for considerably more variability. Relative efficiency of selection between the two systems is also an important consideration (Davis *et al.*, 1985). Francis *et al.* (1978b, c) noted an increase in coefficients of variation in intercrop, which decreased efficiency of selection. While this can be overcome by increasing plot size and replications (Davis *et al.*, 1981), there is the concern that additional time and cost may be involved. Selection efficiency was similar between cropping systems in this study. Observed response to direct and indirect selection were comparable for five of seven traits examined, as were heritability estimates. However, genotype x environment interactions produced conflicting results between locations with respect to direct and indirect selection for yield and pods per plant (data not shown).

The results are consistent with the observation that a majority of top yielding lines in sole crop were also top yielding in intercrop. It appears from the work that selection in sole crop, although at a lower selection intensity, retains an adequate sized sub-sample of the initial population, which also performs well in intercrop. The results seem to provide support for the concept of testing a small sample of breeding lines in intercrop after making initial selections in sole crop. However, additional experiments with different genetic materials will be required to confirm the results shown here.

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