ADAPTING VARIETIES FOR INTERCROPPED SYSTEMS IN THE TROPICS

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Abstract

Farmers with limited land resources in the tropics have traditionally intercropped (or multiple-cropped) their land to minimize risk and provide a stable source of income and nutrition for the family, while maximizing returns under low levels of technology. Crop varieties have been selected by generations of farmers to fit this cropping pattern. Improved cereals and legumes developed under monoculture conditions may not be optimum for an intercropped system. Variety by system interactions suggest that emphasis be given to developing varieties which can be used across a wide range of the most common cropping systems in a region. Selection should include varietal characteristics which increase production of component crops and entire complex systems. A series of trials with the maize/bean system has given information on optimum population combinations, planting dates, weed control and other cultural practices, which are useful in identifying plant types of these two species which give maximum production and optimum return from the system in a specific location. These genotype by system studies include a range of maize plant types, bush bean varieties, and climbing bean varieties.

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INTRODUCTION

Intercropping of more than one plant species on the same land during the same season is widespread on the subsistence farms in developing countries of the tropics. Agricultural research in the tropics, however, has focused on the development of new technology directed toward the efficient production of single crops. With a shift to single crop systems, improved cultural practices, chemical fertilizers, pesticides, and other modern inputs, the productivity of tropical soils has improved. Crop varieties have been developed for monocrop culture, and considerable progress has been made in increasing yield potential for those farmers who have put capital and available technology to work in the better agricultural regions.

We question the total validity of this approach to crop improvement. New technology has yet to reach small farmers who produce the food crops in many tropical countries. They insist on preserving traditional systems even when other alternatives, including new varieties best suited for monoculture cropping, become available. Although their decision-making criteria are poorly understood, diversity of diet and income source, stability of production, reduced insect and disease incidence, efficient use of family labor, and intensive production with limited land resources appear to be important. It is critical that we understand the farmer's production systems into which new varieties and other technological advances are to be introduced, and evaluate new varieties in a range of environments and systems in which food crops are produced.

Varietal improvement methodology for intercropping systems in the tropics must reflect:

1. Previous varietal selection for these complex systems

Review of the literature and recent communications with a number of specialists in Asia, Africa and Latin America indicate to us that limited attention has been given to selection of varieties for specific multiple cropping systems, although there has been conscious selection for certain characteristics which made new varieties better adapted to both intercropping and modern monoculture.

2. Need for a breeding program designed for complex cropping schemes

Results from work in the Centro Internacional de Agricultura Tropical (CIAT) on maize/bean systems and in the literature indicate a variety by system interaction for some crops and systems. Crop selection for complex systems includes certain traits which will increase yield potential in a range of systems and environments.

3. Design of an efficient procedure for selection in more than one system

A scheme which is currently used in CIAT for maize, climbing beans, and bush beans is presented. Field results from this work are preliminary, and must be confirmed over seasons and locations.

This procedure is being developed for bean improvement in Latin America. We conclude with a discussion of traits which appear to favor varieties in intercropping systems. An integrated improvement program must include on-farm trials as an indispensable step in the selection and testing procedure.

PAST RESEARCH ON INTERCROPPING

Research attention has been given to intercropping in India (Aiyer, 1949; Kanwar, 1970; Mahapatra et al., 1973; Singh, 1970; Swaminathan, 1970), Taiwan (Chang, 1965; Kung, 1969), Philippines (Bradfield, 1973; IRRI, 1972, 1973, 1974; Herrera and Harwood, 1973), Nigeria (Andrews, 1972; Baker, 1974; Norman, 1974), Tanzania (1974a, 1974b), Uganda (Willey and Osiru, 1972), Mexico (Turrent and Laird, 1972), Colombia (Flor and Francis, 1975; Higuita, 1971), El Salvador (Chacón and Barahona, 1974), the Caribbean zone (Jolly, 1956), and Costa Rica, where a pertinent bibliography recently has been published (IICA, 1974). An excellent survey was published by Dalrymple (1971). In these papers the importance of multiple cropping for certain crops and regions has been described and at times quantified. In several reports, the differences among varieties of specific crops have been explored. Traits which have proven useful in intercropping systems also have been identified in traditional and improved varieties.

1. Importance of Intercropping Systems

Several papers in this symposium have outlined the occurrence and importance of intercropping systems in the tropics (Andrews, 1975), and more specifically in Asia (Harwood, 1975), Africa (Okigbo, 1975), and Latin America (Pinchinat, 1975). It is estimated that 98% of cowpea, probably the most important legume in Africa, is grown in association with other crops (Arnon, 1972). Norman's survey in northern Nigeria (1974) reports 83% of crop land in mixed cropping. In Colombia 90% of the bean crop is grown in association with maize, potato and other crops, while in Guatemala 73% of bean production is from associated cropping, principally with maize (Gutiérrez et al., 1975). Eighty percent of the beans in Brazil are grown with other crops, principally maize (IICA, 1969). We estimate that in the Latin American tropics 60% of the maize is associated with other crops. Dalrymple (1971) surveyed the use of these cropping systems in less developed countries throughout the tropics, and concluded that multiple cropping is a widespread practice throughout the world.

2. Research Results on Intercropped Systems

Agronomic trials with intercropped systems have concentrated on such variables as relative plant population of component crops, planting dates, fertilizer treatments, and spatial orientation of the crops. High-yielding and early-maturing varieties have been used in these tests, at times with a preliminary screening to identify those varieties most suited to a given climate or system. Examples are varieties of sweet potato in sugar cane (Shia and Pao, 1964; Tang, 1963, 1964), mung beans, soybeans, cowpea and sweet potato in maize (IRRI, 1972, 1973, 1974), beans with maize (Chacón and Barahona, 1974), and cotton associated with peanuts (Rao et al., 1960). Testing varieties in two or more systems has produced variable results. Baker (1974) emphasized the importance of a new variety's capacity to increase yields over old varieties with available technology. In a test of four sorghum varieties in monoculture and intercropped with millet, yields of sorghum were consistently higher in the intercropped system and maintained about the same rank order in the two systems.

In screening 12 promising soybean cultivars in Tanzania, Finlay (1974b) found that intercropping with maize, sorghum and millet reduced yields of the soybeans to 37%, 43% and 18% of the 15.2 qq/ha monocrop yield (average of 12 varieties). A later report by Finlay (1974a) asks if material available for monoculture systems is suitable for intercropping, and if varieties of legumes will maintain their yield ranking when intercropped with cereals. He has also evaluated 21 varieties of maize in monoculture and with both soybean and cowpeas intercropped, but no results were included in the preliminary report.

Yields of 12 mung bean varieties intercropped with maize in the Philippines were reduced to 37% of the monocrop potential in two seasons (IRRI, 1973). Relative yields of the varieties tested ranged from 24 to 43% of the monocrop. Highest-yielding cultivars suffered most from competition. Nine climbing bean varieties were tested in Boliche, Ecuador by Buestan (1973), intercropped with normal (INIAP-515) and dwarf (Brachytic) maize. There were no differences in maize yields across the nine bean varieties, but four of the bean varieties showed significant yield differences between the contrasting maize plant types used as support.

Maize-bean intercropping in two seasons in El Salvador (Chacón and Barahona, 1974) showed highest total yields from a combination of the Sesuntepeque bush bean variety and the maize hybrid H-3.

3. Plant Characteristics and Intercropping Systems

Varietal traits which are useful for intercropping have been described in the literature. Photoperiod insensitivity allows the planting of a variety at any time during the year, and gives flexibility to new systems which require planting outside the traditional dates for a region and crop (Dalrymple, 1971; Swaminathan, 1970). Early maturity permits a more intensive organization and greater flexibility for intercropped or relay cropped systems (IRRI, 1972; Herrera and Harwood, 1973; Rao et al., 1960; Sindagi and Ansari, 1969). Short and non-lodging plant types of some crops have been selected for nitrogen responsiveness and reduced foliage and light competition in crop associations (IRRI, 1972, 1973; Sindagi and Ansari, 1969; Swaminathan, 1970). Population responsiveness allows greater flexibility for varying the proportions of crops in a mixture according to present economic returns, and in obtaining the highest total field population of an intercropped system (IRRI, 1973; Swaminathan, 1970).

4. Selection of Crops for Intercropped Systems.

Although certain characteristics of new varieties are helpful when these species are intercropped, there is only limited evidence that conscious selection has been made by plant breeders for intercropped systems. We conclude that most selection has been performed by farmers in the developing tropics, who have grown crops under their specific systems for a number of years, and who have consistently chosen seed from individuals and varieties that performed best in the intercropped scheme. This is confirmed by correspondence from a number of colleagues currently acquainted with small farm agriculture.[3/]

IMPROVING PRODUCTIVITY OF INTERCROPPED SYSTEMS

The first step in improving crop species for intercropped systems is to decide if specific genetic selections are needed for specific cropping systems. An information base is needed on principal cropping systems and factors limiting production. The potentials for increasing intercropped yields with improved germplasm are a function of the corresponding monocrop potentials of each component and the relative reductions in yields when these crops are combined. Variety by system interactions may require more than a single breeding strategy for a specific crop. Using beans and maize as examples, we propose a scheme for developing improved varieties for farmers of tropical Latin America.

1. Predominant Cropping Systems in the Region

In Latin America certain crops are grown in monoculture, including

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3/ Personal Communications. 1975. D.J. Andrews, ICRISAT, Hyderabad, India; S. Bradfield, Dept. Anthropology, Kalamazoo College; D.F. Dalrymple, U.S.D.A., Washington; D.D. Harpstead, Dept. Crops and Soils, Michigan State Univ.; R.D. Hart, Alexandria, Virginia; R.R. Harwood, IRRI, Los Baños, Philippines; E.A. Kueneman, Dept. Plant Breeding, Cornell Univ.; H.G. Nasr, Amer. Univ. Beirut; A. Pinchinat, CATIE, Turrialba, Costa Rica.

sugarcane, sorghum, lowland rice, cotton, wheat, and barley. Genetic improvement of these crops concentrates on evaluation in single-crop culture, although the same solution may not be appropriate for these crops in other areas, for example sorghum in Africa or sugarcane in Taiwan. Other basic food crops of the Americas -- cassava, maize, beans, potato, yams -- are most frequently found associated or intercropped. To improve these crops, researchers must consider the frequency of principal systems in which these crops are grown. This assessment should be quantitative with respect to crops and production-limiting factors, and representative of the country or region.

Examples of such a survey are available for cassava and beans in Colombia. A detailed study of factors limiting cassava production has included 300 farms in five zones of Colombia, with three field visits during the crop cycle. In this survey, 60% of the farms and 70% of the area were monoculture cassava; the remainder has a variety of crop combinations (CIAT, 1974).

Surveys on factors limiting bean production (Gutiérrez *et al.*, 1975; IICA, 1969) indicate that up to 80% of the total bean area in Latin America is intercropped. Precise studies on limiting factors in beans are in progress, using the methodology outlined by Andersen and colleagues (Andersen *et al.*, 1974).

2. Present Crop Yields and Potentials for Improvement

Reported experiment station yields for beans in Latin America are generally several times greater than those obtained in farmer's fields, where new varieties will be introduced into complex cropping systems. Bean production in Latin America, summarized by Gutiérrez *et al.* (1975) and listed by country in Table 1, averages 600 kg/ha. Mexico, the second largest bean-producing country in Latin America, is not included in the table.

Table 1. Bean production for nine countries of Latin America reported by Gutiérrez *et al*. (1975).

Country	Year	Area	Production	Yield
		(ha)	(tons)	(kg/ha)
Brazil	1970	3,484,778	2,211,449	635
Colombia	1971	68,000	39,000	583
El Salvador	1971	39,900	21,200	670
Guatemala	1971	185,269	61,154	331
Honduras	1971	72,700	55,400	762
Nicaragua	1969	59,635	44,054	738
Panamá	1971	16,900	5,410	320
Perú (coast)	1971	60,750	47,993	790
Dominican Republic	1971	37,500	28,125	750

These national average yields are low compared to experimental results obtained by Howeler (CIAT, 1974; personal communication, Bean Program, CIAT, 1975) in preliminary CIAT trials in four locations in Colombia and Ecuador (Table 2). Under good management at three altitudes, the best varieties produced over 2,500 kg/ha in Palmira (1000 m), Popayan (1600 m) and Boliche (14 m). Yields of 1,500 kg/ha were obtained with one variety in the lowland location Monteria (40 m). These are all early, black-seeded bush bean varieties. Varieties in these trials represent only our initial evaluation and preliminary selection of collections from Latin America. Although some varieties came from national programs, no crossing nor pure line selection using the more than 10,000 collections in the germplasm bank in CIAT was done prior to these initial trials.

The potential for yield improvement is also promising for climbing beans. Preliminary monocrop tests with artificial support and intensive management consistently have given experimental plot yields greater than 4,000 kg/ha (1974; personal communication, Y. Hayakawa and D. Laing, Bean Program, CIAT, 1975) in trials at CIAT. Experimental results from several seasons, varieties and densities (Table 3) suggest that optimum densities vary with variety and season. High populations of climbing beans give high yields and profits at current prices. These preliminary results from diverse trials demonstrate a yield potential which has not been exploited, and these varieties were relatively unselected materials that have not as yet been improved in the breeding program.

Characteristics of the climbing types which distinguish them from the bush phenotype, and which may be related to yield potential, include taller plant structure, larger number of nodes and pods per unit land area, higher leaf area index, later flowering and maturity, and greater bean and total

Table 2. Yields of superior varieties and selections of bush beans at four locations (CIAT, 1974; personal communication, R. H. Howeler, Bean Program, CIAT, 1975).

Location (season)	Variety or selection	Density (1000/ha)	Yield (kg/ha)
Popayan, Colombia	Porrillo Sintetico (P566-C)	280	2,857
(1974 A)	6536-1-T-T (P538-A)		2,714
	6589-1-T-T (P512-A)		2,657
	6575-M-T-T (P362-A)		2,655
	ICA Pijao (Linea 32)		2,628
	(Of 45 varieties in test, 8>2,500 kg/ha, 35>2,000 kg/ha).		
Montería, Colombia	Porrillo Sintetico (P566-C)	213	1,523
(1974 B)	ICA Tui		1,184
	6545 Porrillo #1		1,104
	6554		1,095
	Linea 29		1,074
	(Of 36 varieties in test, 1>1,500 kg/ha, 8>1,000 kg/ha).		
Boliche, Ecuador	ICA Pijao (Linea 32)	280	3,135
(1974 B)	7998-1-T-T (ICA Tui)		3,056
	6535-1-T-T		3,050
	6541		2,864
	6536-1-T-T (P538-A)		2,826
	(Of 30 varieties in test, 13>2,500 kg/ha, 25>2,000 kg/ha).		
Palmira, Colombia	Porrillo Sintetico (P566-C)	333	2,743
(1974 A)	150-1-1 (P560-B)		2,720
	6530 Var 51052		2,653
	141-M-1 (P459-C)		2,522
	6589-1-T-T		2,342
	(Of 56 varieties in test, 4>2,500 kg/ha, 15>2,000 kg/ha).		
Palmira, Colombia	ICA Pijao (Linea 32)	333	2,616
(1974 B)	Porrillo Sintetico (P566-C)		2,391
	8251-1-1-T-T		2,390
	6545 Porrillo #1		2,384
	Linea 29		2,241
	(Of 56 varieties in test, 1>2,500 kg/ha, 11>2,000 kg/ha).		
Palmira, Colombia	141-M-1 (P459-C)	333	3,320
(1975 A)	Jamapa		3,090
	P511-A		3,070
	P302-A		2,980
	P560-B		2,960
	(Of 40 varieties in test, 26>2,500 kg/ha, 39>2,000 kg/ha).		

Table 3. Yields of climbing bean varieties grown with artificial support in CIAT, Palmira, Colombia (CIAT, 1974; personal communication, Y. Hayakawa and D. Laing, Bean Program, CIAT, 1975).

Season	Variety	Density (1000/ha)	Yield (t/ha)
1974 A	Trujillo 3	1,000	5.65
	Trujillo 2	1,000	5.59
1974 B	N-315-61-1-5-1	200	5.03
	PI 282-063	200	4.47
	Trujillo 2	200	4.10
	Trujillo 3	200	4.04
1975 A	PI 310-739	400	4.50

dry matter yields.

3. Effects of Intercropping

There is a potential for increasing yields of monocrop beans, using improved varieties, high populations and pathogen-free seed. Intercropping reduces bean yields in most seasons and systems when beans and maize are grown together. Table 4 illustrates a 20% yield reduction of bush beans grown with an evenly spaced maize population of 44,000 plants/ha. A more traditional maize system, with three or four plants in widely-spaced hills, produced no significant reductions in bean yields. Maize yields were unaffected by the spacing treatments.

Relative planting dates of the two crops influence yields of the bush beans. In the trial reported in Table 5, bean yields were reduced from 939 kg/ha in monocrop to less than 400 kg/ha when maize was planted before the beans. A 15-day advantage for the beans gave highest yields, a result confirmed by small farmers in the vicinity who use this practice. Land equivalent ratios (Bantilan and Harwood, 1973) were highest when beans were planted after the maize.

The effects of planting system and population are shown for three methods of intercropping maize and bush beans in Table 6. Higher bean populations increased yields, but intercropping reduced yields from the monocrop levels for this red bean variety (ICA Guali).

Yields of bush beans and climbing beans intercropped with normal and dwarf maize are reported in Table 7. Monoculture yields of the dwarf (brachytic-2) hybrid maize were higher than those of the normal hybrid (ICA H-207), when each was planted at recommended densities. Total biological yields of maize did not differ significantly between these two hybrids

Table 4. Yields of beans and maize with four planting systems, CIAT, 1973 B (Flor and Francis, 1975).

Planting System[1/]	Yield	
	Bean	Maize
	(kg/ha)	
Bean	1,330a[2/]	
Bean and Maize (1 plant each 25 cm)	1,021c	5,124a[2/]
Bean and Maize (2 plants each 50 cm)	1,066bc	5,290a
Bean and Maize (3 plants each 75 cm)	1,267ab	4,518a
Bean and Maize (4 plants each 100 cm)	1,206abc	4,446a

1/ Bush bean variety ICA Guali planted at 220,000/ha; yellow brachytic maize planted at 44,400/ha.

2/ (Yields followed by same letter in each column not significantly different (5% level).

Table 5. Yields of beans and maize with varied planting dates, CIAT, 1974 A (Flor and Francis, 1975).

Planting Dates[1/]	Yield		LER[3/]
	Bean	Maize	
	(kg/ha)		
Maize (monocrop)		7,270a[2/]	
Maize 15 days before beans	365c[2/]	5,730bc	1.18
Maize 10 days before beans	400c	5,840bc	1.23
Maize 5 days before beans	394c	5,040c	1.11
Simultaneous planting	500bc	5,710bc	1.32
Beans 5 days before maize	483bc	6,910ab	1.46
Beans 10 days before maize	516bc	7,230a	1.54
Beans 15 days before maize	703ab	6.760ab	1.68
Beans (monocrop)	939a		

1/ Bean variety ICA Pijao (Linea 32) planted at 300,000/ha; maize hybrid ICA H-207 planted at 40,000/ha.

2/ Yields followed by same letter in each column do not differ significantly (5% level).

3/ Land equivalent ratio (LER) described by Bantilan and Harwood (1973), LER = (maize yield in association/monocrop maize yield) + (bean yield in association/monocrop bean yield).

Table 6. Yields of beans and maize with several planting systems, CIAT, 1974 B (Flor and Francis, 1975).

Planting System[1]	Bean Density	Yield		LER[3]
		Bean	Maize	
	(1,000/ha)	(kg/ha)		
Maize (monocrop)			3,767a[2]	
Maize with beans in same row	111	896b[2]	4,139a	1.78
Maize with beans in parallel row	111	693c	4,162a	1.63
Maize with beans in two parallel rows	222	1,008b	4,239a	1.88
Beans (monocrop)	222	1,326a		

1/ Bean variety ICA Guali, maize variety yellow brachytic at 44,400/ha.

2/ Yields followed by same letter in each column do not differ significantly (5% level)

3/ Land equivalent ratio (LER).

Table 7. Yields of bush and climbing beans with normal and brachytic maize, CIAT, 1975 A.

System	Density		Yield			Maize Harvest Index	LER[2/]
	Beans	Maize	Beans	Maize Grain	Maize Total		
	(1,000 plants/ha)		(kg/ha)	(kg/ha)	(kg/ha)		
Bush bean (ICA Pijao)	222		1,738c[1/]				
Normal maize/Bush bean	155	44	845d	7,631bc[1/]	14,268a[1/]	.46ab[1/]	1.65
Brachytic maize/Bush bean	177	65	647de	8,769a	15,564a	.48a	1.44
Climbing bean (PI 282-063)	44		2,148b				
Normal maize/Climbing bean	44	44	429ef	7,318c	15,839a	.40bc	1.30
Climbing bean (PI 282-063)	65		2,456a				
Brachytic maize/Climbing bean	65	65	220f	8,153ab	15,634a	.45abc	1.08
Normal maize (ICA H-207)		44		6,535d	15,014a	.38c	
Brachytic maize (ICA H-210)		65		8,205ab	15,796a	.45abc	

1/ Yields in same column followed by same letter do not differ significantly (5% level); bean yields with 14% moisture, maize grain yields with 15% moisture, and maize total dry matter yields based on absolute dry weight.

2/ Land equivalent ratio (LER).

nor among systems. Higher yields of dwarf maize resulted from higher harvest index (proportion of grain to total yield). Bush bean yields were reduced by 52% and 63% when intercropped with normal and dwarf maize, respectively. These yield reductions in bush beans intercropped with maize were the result of fewer racemes/plant (5 in intercrop vs. 9 in monocrop beans), fewer pods/plant (9 versus 14), and reduced pod and stem weight/plant. Harvest indices were not affected by system, with the same relative dry matter distribution among plant parts in the three treatments. Yields were reduced 80% when climbing beans were grown with normal maize, and 90% when grown with dwarf maize, compared to monoculture climbing beans at the same plant densities.

Bean yield reductions also were due to competition from maize in the intercropped system, and are related to the changes in yield components shown in Table 8. Plant height of beans was unchanged, but lower numbers of racemes, pods, leaves, and branches per plant were observed in the intercropped climbing beans. Competition reduced dry weights of all bean plant components, but harvest index was not altered substantially. Subsequent trials with higher bean populations, modified planting dates and physical orientation of the two crops are designed to reduce the apparent interspecies competition and increase bean yields using maize and other support systems.

Yields of bush beans and soybeans, intercropped with maize and rice, are shown in Table 9. Legume yields were reduced by association with maize, while the yields increased slightly (non-significantly) when these legumes were intercropped with rice. There were no significant differences in maize grain or total biological yield, nor in harvest index. In all trials of spacing, densities, planting dates and physical orientation of intercropped systems, bean yields are low compared to the experimental yields reported in Tables 2 and 3.

Table 8. Yield components of climbing beans grown in two densities and two systems, CIAT, 1975 A (Yield components from 4-plant samples, final yield in kg/ha from complete plot harvest).

System	Plant Height	Racemes per Plant	Pods per Plant	Leaves per Plant	Branches per Plant	Stems	Leaves	Pods Seed	Harvest Index	Bean Yield
	(cm)					(grams/plant)				(kg/ha)
Climbing bean monocrop (44,400 plants/ha)	275a[1/]	27a[1/]	46a[1/]	52a[1/]	3.8a[1/]	18.5a[1/]	25.2a[1/]	55.0a[1/]	.56	2,148b[1/]
Climbing bean monocrop (65,000 plants/ha)	247a	19b	37a	38b	2.8b	14.2b	20.0b	37.8b	.53	2,456a
Climbing bean Inter-cropped Normal Maize (44,400 plants/ha)	242a	6c	10b	16c	1.0c	4.8c	10.0c	15.0c	.50	429c
Climbing bean Inter-cropped Brachytic Maize (65,000 plants/ha)	239a	3c	5b	11c	1.0c	3.2c	4.8d	6.5c	.43	220c

1/ Numbers in each column followed by same letter do not differ significantly (5% level).

Table 9. Yields of bush beans, soybeans, and maize in several combinations, CIAT, 1975 A.

System	Density		Yield		LER[3/]
	Legume	Maize	Legume	Maize	
	(1,000 plants/ha)		(kg/ha)		
Normal Maize (ICA H-207)		44		7,221a[2/]	
Bush bean (ICA Pijao)	200		2,033bc[2/]		
Soybean (ICA Pance)	200		2,910a		
Maize/Bush Bean	200	44	1,033d	6,926a	1.47
Maize/Soybean	200	44	1,550c	6,525a	1.44
Maize/Rice[1/]		44		8,195a	
Bush bean/Rice[1/]	200		2,223b		
Soybean/Rice[1/]	200		3,025a		

1/ Rice not yet harvested.

2/ Yields in each column followed by same letter do not differ significantly (5% level).

3/ Land equivalent ratio (LER).

Similar trials are planned, using high yielding cultivars, pathogen-free seed, and the best agronomic system based on results to date.

4. Variety by System Interactions

The decision to screen and select promising germplasm using more than one system depends on the magnitude of variety by system interactions, as shown by the relative performance of different cultivars under two or more systems. Table 7 quantified the reduction in bush and climbing bean yields when each was grown with two types of maize, normal and dwarf. Germplasm testing in a high return monocrop system with artificial support would lead to selection of the climbing types, as compared to bush types. These climbers would not be optimum for planting with maize, where the bush types have shown a yield advantage in agronomic systems tested to date.

In Boliche, Ecuador, relative yields of nine climbing bean cultivars were determined from plantings with contrasting normal and brachytic maize (Buestan, 1973). The data summarized in Table 10 show significant yield differences among the bean varieties tested. A comparison of the bean yields between the two intercropped systems revealed non-significant correlations for yield (r = 0.265) and for rank order (r = 0.361). Selection of a bean variety for one system would therefore not provide the best bean for a different system. In this trial the correlation coefficients were negative (non-significant) for yields of beans and maize (r = -0.229 for normal, r = -0.509 for brachytic), which illustrates a differential competition between the two crops in these two maize support systems.

Using soybean data reported by Finlay (1974b), we have calculated the simple correlations of yield and rank between monoculture soybeans and three intercropping systems with cereals (Table 11). These correlations were not

Table 10. Yields of nine climbing bean collections associated with two contrasting maize types, Boliche, Ecuador, 1973 B (Buestan, 1973).

Climbing Bean Variety	Beans Associated with Dwarf Maize Rank	Beans Associated with Dwarf Maize Yield	Beans Associated with Normal Maize Yield	Beans Associated with Normal Maize Rank
		(kg/ha)	(kg/ha)	
Panamito	1	1,343a 1/	780bc 1/	5
73 VUL 5669-M	2	1,025b	695cd	6
73 VUL 5585-M	3	1,003b	1,081a	2
Pata de Paloma	4	954b	991ab	4
73 VUL 5488-M	5	938b	1,005a	3
73 VUL 5646-M	6	882bc	1,102a	1
73 VUL 5723-M	7	811bc	669cd	7
73 VUL 5643-M	8	803c	542d	9
73 VUL 5583-M	9	708c	600cd	8

1/ Bean yields in same column followed by same letter do not differ significantly (5% level); within a variety, yields connected by an underscore across the two systems do not differ significantly (5% level).

Table 11. Yield and rank order correlations for soybean production in different intercropping systems (Correlations for data reported by Finlay, 1974b).

Soybean Systems	r (yield)	r (rank)
Monocrop vs. Intercropped with Maize	.506	.455
Monocrop vs. Intercropped with Sorghum	.372	.432
Monocrop vs. Intercropped with Millet	.398	.372
Intercropped with Maize vs. Intercropped with Sorghum	.595*	.392
Intercropped with Maize vs. Intercropped with Millet	.444	.336
Intercropped with Sorghum vs. Intercropped with Millet	.692**	.601*

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

significant. Simple correlations between soybean yields and rank among several different intercropped systems with cereals were significant. Among the intercropped systems, yields of soybeans intercropped with sorghum were related to yields of soybean intercropped with the other two cereals.

Correlations of mung bean yields in monocrop versus maize associations (calculated from data of R.R. Harwood, IRRI, 1973, 1974) gave a negative, non-significant r-value for yield (r = -0.339) and rank order (r = -0.098) over two seasons in 1973. Similar calculations for 1974 gave positive, non-significant r-values for yield (r = 0.514) and rank order (r = 0.434). Monocrop yields of eight varieties common to the trials of both years showed a positive, non-significant r-value (r = 0.465) across years, with the same results for mung beans intercropped with maize (r = -0.045). This variety by season interaction complicates the selection of stable, high-yielding varieties.

Bean yields of seven varieties intercropped with maize (data from Chacon and Barahona, 1975) were not significantly correlated over two seasons (r = 0.218). There was no significant correlation of maize yields in two seasons across bean varieties (r = 0.318). Bean production was negatively correlated with maize production (r = -0.858, significant at 1% level).

The only significant association between intercropped and solo performance among varieties was found in the sorghum trial reported by Baker (1974). Monocrop sorghum yields were highly correlated with yields of sorghum intercropped with millet (r = 0.947, significant at 1% level)

This synthesis and analysis of existing data from intercrop studies confirms the importance of variety by system interactions. In reaching a decision on which system or systems to use in a breeding program, one must confront the circular problem inherent in the evaluation of genetic material in new systems. With a change in fertility, plant densities, or cropping system, selected materials with superior performance under a previous system may not be superior. It is necessary to select germplasm under the new conditions. As systems evolve and improve, it is necessary to test each cycle of promising selections under current cultural practices. Conversely, optimal populations, planting dates, soil fertility, physical orientation and species balance in mixed crops should be confirmed regularly using the latest varieties.

The costs of implementing more than one system in a breeding program depend on the stage of germplasm development at which selection for intercropping is initiated. The relative advantage of moving large numbers of crosses and selections through one program, versus a reduced number through two programs, must be considered.

The decision on a breeding methodology depends on yield limitations in prevalent cropping systems, potentials of monocrops and intercropping, and variety by system interactions.

EVALUATION OF GERMPLASM FOR INTERCROPPED SYSTEMS

The importance of maize-bean intercropping in the Latin American tropics makes it essential that we consider these systems in the development of new germplasm. With evidence that variety by system interaction exists for maize-bean and other intercrop systems, CIAT has begun to test a number of promising varieties in two or more systems involving these two crops. The best agronomic recommendations from previous intercropping studies have been followed in planting the first cycle which is currently in the field. These evaluation procedures are described below.

1. Maize evaluation in three cropping systems

In addition to maize monoculture production in all parts of the Andean zone, Central America and Brazil, there are large areas where maize is cultivated with bush beans (Brazil, Central America and Mexico) and with climbing beans (highland areas throughout Latin America). These three systems are included in an initial test to evaluate 15 full-sib maize families representing several plant types with reduced height and apparent efficiency. These systems, shown in Figure 1, have the following characteristics:

a. Monoculture Maize - density 80,000 plants/ha.

b. Intercropped Maize, with Bush Bean - maize density 40,000 plants/ha with bush bean (ICA Pijao) density 300,000 plants/ha.

c. Intercropped Maize, with Climbing Bean - maize density 40,000 plants/ha with climbing bean (PI 282-063) density 300,000 plants/ha.

Evaluation of the maize families will be based primarily on maize yield, resistance to lodging, and bean yields. Maize and bean yields at current market values will also be used to determine an economically weighted rank order of the 15 maize genotypes.

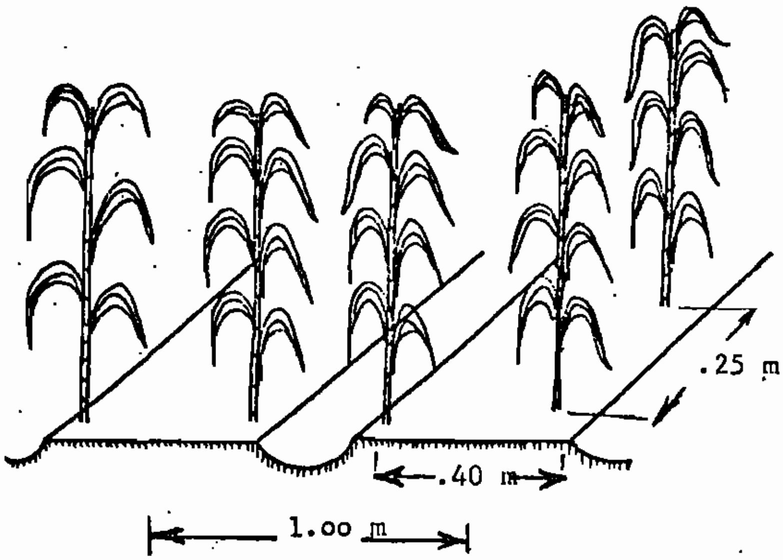
2. Bush bean evaluation in two cropping systems

An evaluation of bush beans, in monoculture and intercropped with maize, has been initiated with nine bean selections. These include the best local variety (ICA Pijao), the most promising variety from tests at several locations (Porrillo Sintetico), and other promising selections. The systems shown in Figure 2 are characterized by:

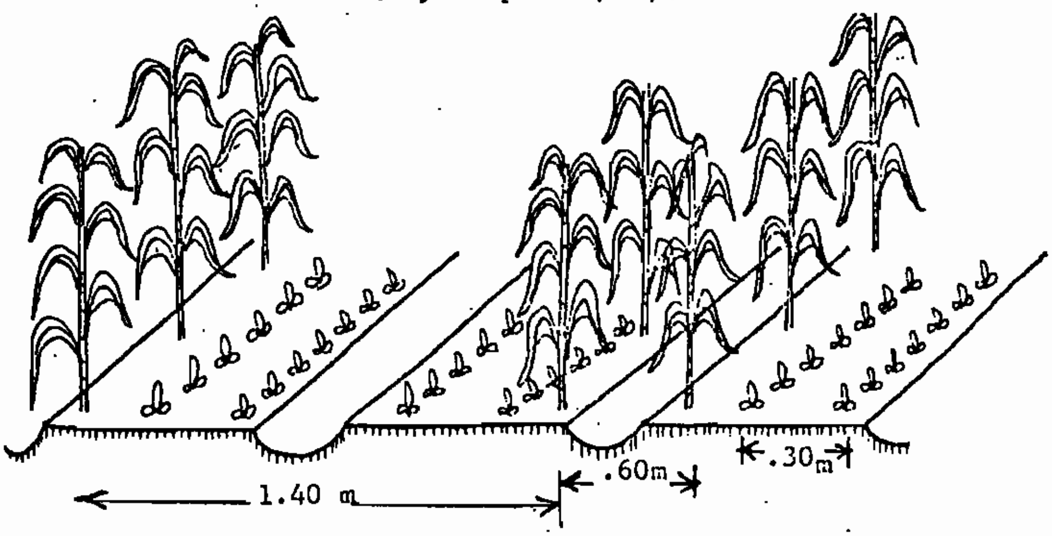
a. Monoculture Bush Beans - density 350,000 plants/ha.

b. Intercropped Bush Beans, with Maize - bean density 350,000 plants/ha, with maize (ICA H-207) density 40,000 plants/ha; beans planted 15 days before maize.

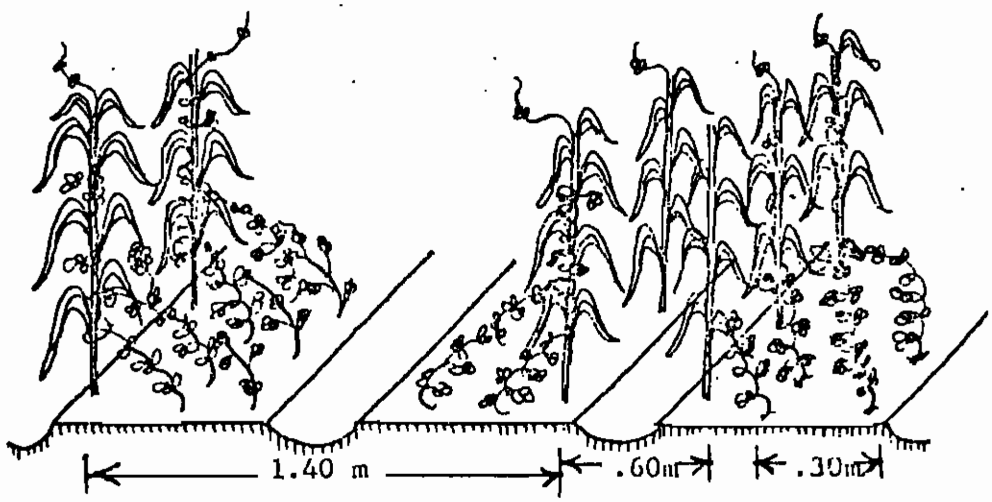
Figure 1. Three agronomic systems for evaluating maize germplasm in CIAT.



1. Monoculture Maize (80,000 plants/ha).

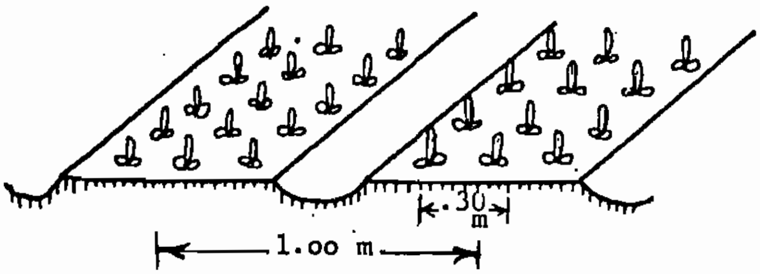


2. Maize (40,000plants/ha) and Bush Bean (300,000 plants/ha).

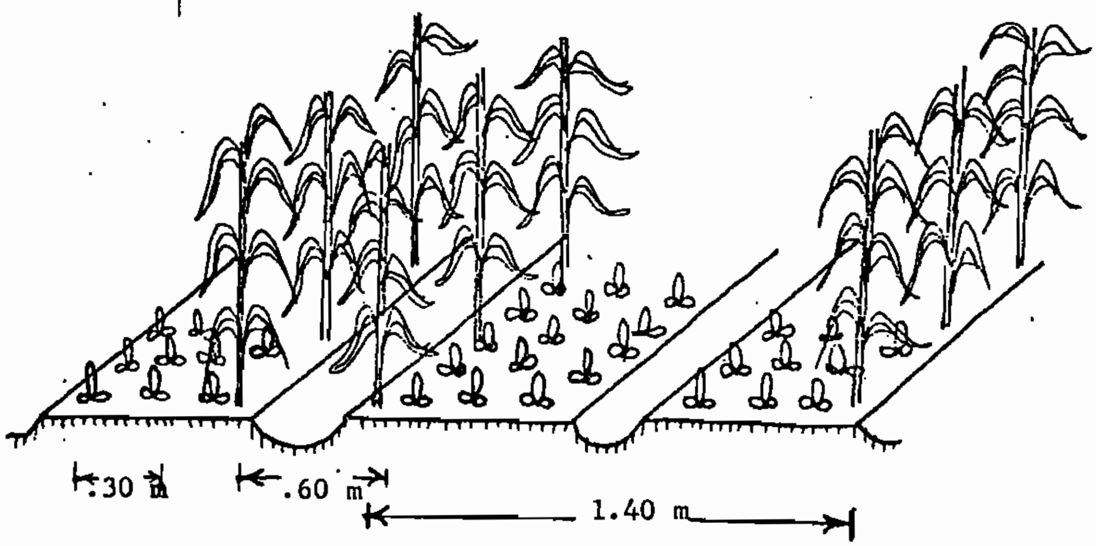


3. Maize (40,000 plants/ha) and Climbing

Figure 2. Two agronomic systems for evaluating bush bean germplasm.



1. Monoculture Bush Beans (350,000 plants/ha).



2. Bush Beans (350,000 plants/ha) and Maize (40,000 plants/ha).

Beans will be evaluated on yields in the two systems, with emphasis on the comparative rank ordering of the nine genotypes between the two systems. Maize yields in the intercropped system will be used as an additional criterion in the evaluation of the total system.

3. Climbing bean evaluation in two cropping systems

Climbing beans are being evaluated in monoculture and intercropped with maize. The nine cultivars include Trujillo, PI 282-063, and other promising lines, monocropped on bamboo and wire trellises with twine guides to support the beans. The same collections are intercropped with a normal maize hybrid (ICA H-207). These systems shown in Figure 3 have the following characteristics:

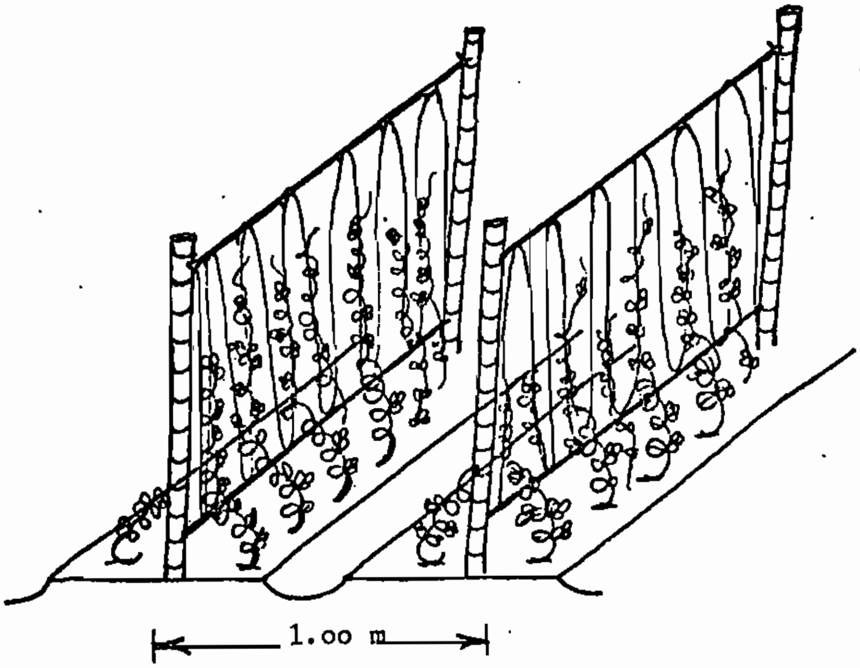
a. Monocrop Climbing Beans with artificial support - density 300,000 plants/ha.

b. Intercropped Climbing Beans, with Maize - bean density 300,000 plants/ha, with maize (ICA H-207) density 40,000 plants/ha.

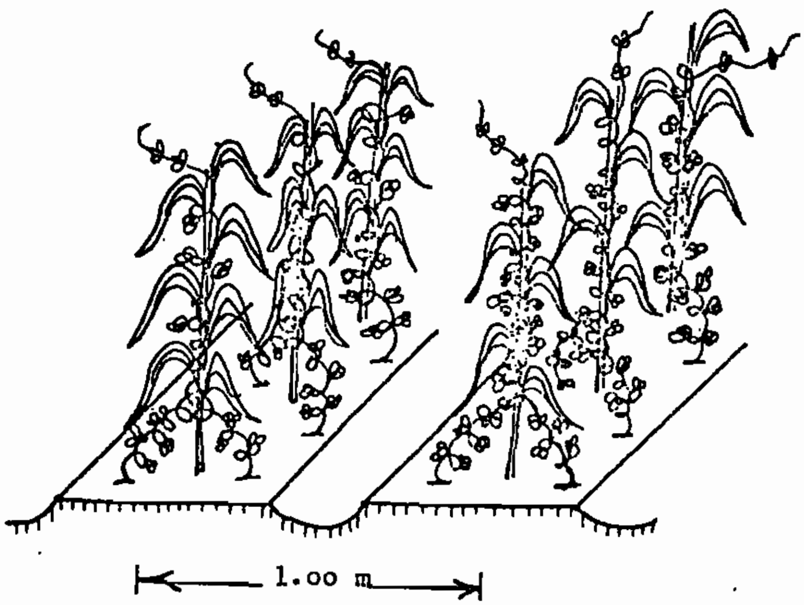
Yields of nine climbing bean cultivars will be used to assign a rank order of varieties in each system. Maize yields may vary with bean genotype, and provide a second criterion for evaluating performance of the system.

From the results of these three tests, repeated in two seasons in each of two locations, decisions will be made on the need to evaluate segregating materials and conduct yield trials with more than one system. If there is little difference in relative performance under different systems, the most economical system can be chosen for breeding work on each crop. These least-cost systems are monoculture maize, monoculture bush beans, and climbing bean intercropped with maize. As suggested earlier, these methodological tests will be repeated in additional locations and in subsequent seasons with new

Figure 3. Two agronomic systems for evaluating climbing bean germplasm.



1. Monoculture Climbing Beans (300,000 plants/ha).



2. Climbing Beans (300,000 plants/ha) and Maize (40,000 plants/ha).

and higher yielding materials, to validate earlier conclusions. Exactly how different the results from contrasting systems must be to justify the cost of two evaluations, and determining the point in an improvement scheme where the two systems should be introduced, are difficult questions that still must be answered. This procedure is designed to give the researcher an objective evaluation of new germplasm in the systems into which it will be introduced.

GENETIC IMPROVEMENT OF VARIETIES FOR INTERCROPPING

As an integral part of this breeding procedure for one or more cropping systems, the desirable characteristics for each crop must be included as selection criteria. If different varietal characteristics are needed for different systems, they must be identified and given priority. Several characteristics are discussed in relation to their importance in monocrop versus intercropped systems.

1. Photoperiod insensitivity is associated with adaptation across latitudes and planting dates, and permits accurate prediction of maturity and allows planting throughout the year. The development of photoperiod insensitive materials is an objective of international programs that are developing cereals, legumes and tuber crops for a wide range of climatic and cultural conditions (Dalrymple, 1971; Swaminathan, 1970), although there may be situations where sensitivity is desirable for a specific crop.

2. Maturity objectives depend on crop and system. Intensive intercrop or relay systems may require early and uniform varieties (IRRI, 1972; Herrera and Harwood, 1973), but there is often a trade off between yield potential and maturity. Where increased yield depends on late maturity in a crop such as beans, the breeding objectives for monoculture versus intercropping may

be different.

3. <u>Short and non-lodging</u> plant types are desirable where the objective is yield response to nitrogen and more efficient production per unit leaf area. Reduced foliage and competition for light, and greater seed or tuber production efficiency, are desirable for component species in an intercropped system (IRRI, 1972, 1973; Swaminathan, 1970). Certain systems require a tall and competitive crop variety, such as a rice variety to compete with weeds, or a strong maize variety to support climbing beans. In tests with sorghum varieties (Baker, 1974), increases in yields of sorghum intercropped with millet, as compared with monocropped sorghum, were correlated with sorghum varietal height (r = 0.921, significant at 5% level).

4. <u>Population response</u> is critical for increasing yields in monoculture and intercropping, especially to exploit dwarfness and more efficient plant types. Competition for light and nutrients can be maximized and highest yields achieved when the density of a responsive variety is increased beyond densities used with traditional varieties.

5. <u>Uniformity of flowering and maturity</u> is desirable in intensive intercrop schemes where two or more crops occupy a limited available time and space (IRRI, 1973). But this creates a high-risk situation when adverse conditions occur during flowering -- a short drought or continuous rains at a critical time reduce yields of most crops.

6. <u>Insect and disease resistance</u> are objectives of most breeding programs, and the relative importance of specific resistance factors varies with the cropping system and the production area under consideration.

7. <u>Yield potential</u> is a product of these factors and others, and the prime objective of nearly all breeding programs.

CONCLUSIONS

An understanding of present and potential cropping systems is essential to successful genetic improvement of crop species. The research procedure includes a study of predominant systems and factors limiting production, a consideration of alternative strategies to solve these problems, and a breeding program designed to remove yield limitations by means of improved varieties. The method described to determine the system or systems for selecting improved maize and bean varieties is an example which may be modified for other cropping systems and climatic zones. Success in plant breeding, agronomic research, and other activities of international and national programs, is measured by increased production at the farm level. The final step in this research process is farm testing of new varieties and cultural practices, and an evaluation of their impact on farm income and family nutrition. This is the potential contribution of crop improvement programs to intercropping systems in the tropics.

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