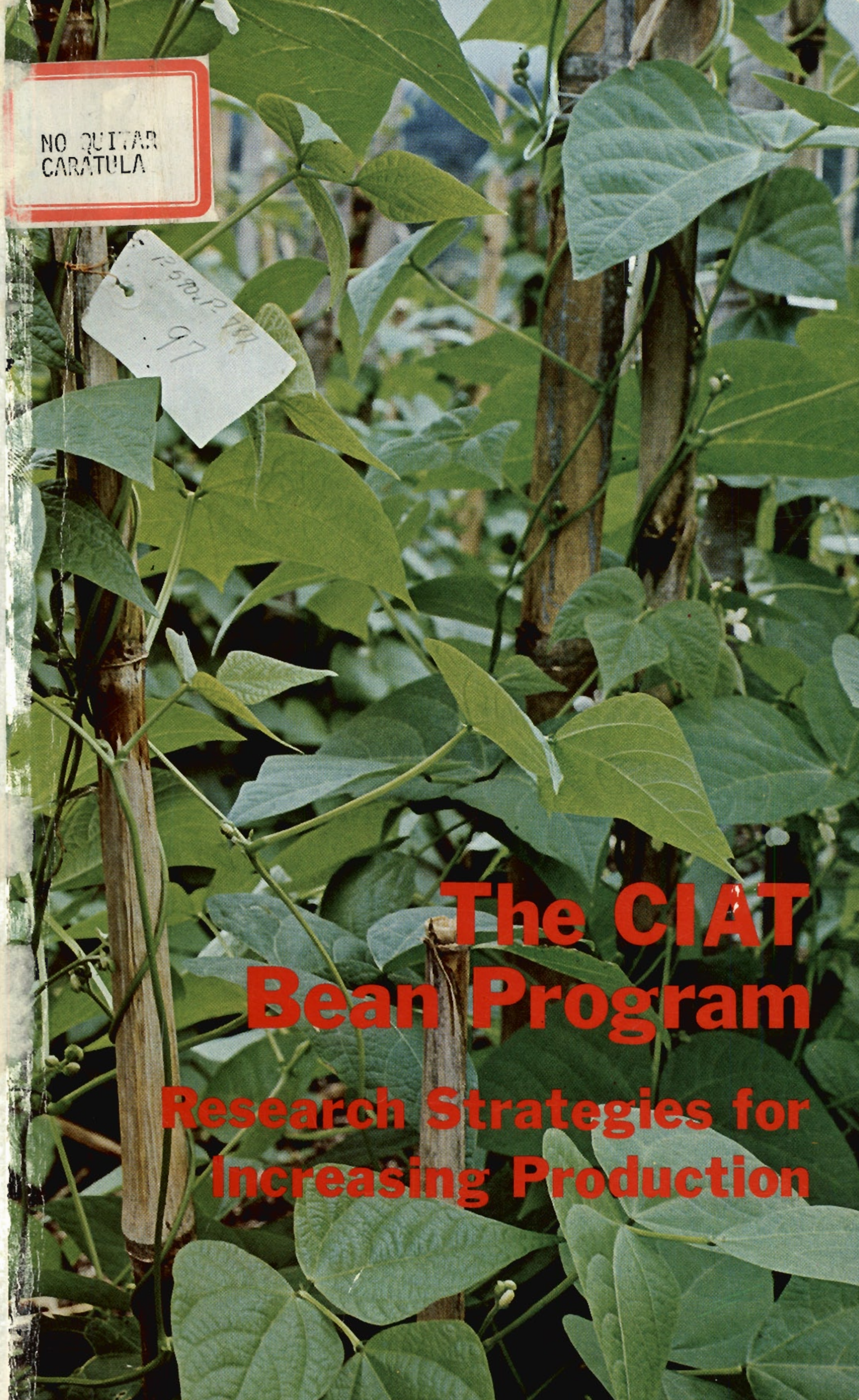

The CIAT Bean Program

Research Strategies for Increasing Production

CIAT is a nonprofit organization devoted to the agricultural and economic development of the lowland tropics. The government of Colombia provides support as host country for CIAT and furnishes a 522-hectare site near Cali for CIAT's headquarters. In addition, the Fundación para la Educación Superior (FES) makes available to CIAT a 184-hectare substation in Quilichao and a 73-hectare substation near Popayán. CIAT also co-manages with the Instituto Colombiano Agropecuario (ICA) the 22,000-hectare Carimagua Research Center in the Eastern Plains of Colombia, and carries out collaborative work on several of ICA's experimental stations in Colombia. Similar work is done with national agricultural agencies in other Latin American countries. CIAT is financed by a number of donors represented in the Consultative Group for International Agricultural Research (CGIAR). During 1981 these CIAT donors are: The Rockefeller Foundation, the Ford Foundation, the International Bank for Reconstruction and Development (IBRD) through the International Development Association (IDA), the Inter-American Development Bank (IDB), the European Economic Community (EEC), the International Fund for Agricultural Development (IFAD), the International Development Research Center (IDRC), and the foreign assistance agencies of the governments of Australia, Belgium, Canada, the Federal Republic of Germany, Japan, Mexico, the Netherlands, Norway, Spain, Switzerland, the United Kindgdom, and the United States. In addition, special project funds are supplied by various of the aforementioned donors, plus the Kellogg Foundation, and the United Nations Development Programme (UNDP).

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Centro Internacional de Agricultura Tropical
Cali, Colombia

Centro Internacional de Agricultura Tropical, CIAT
Apartado 6713
Cali, Colombia

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Contents

Preface

Bean productivity has declined in most countries of Latin America over the last decade. A multidisciplinary research and training team was formed in 1973 at CIAT to work with national programs in developing and transferring new technology to reverse this trend. The team's objectives and strategies were first outlined in a position paper published in 1975. Since then the team has further evolved its methodologies and achievements so it was necessary to update that document. The principal objective of this publication is to outline the CIAT Bean Program's objectives, research strategies and methodologies and research achievements to our collaborators in national programs. We hope this will strengthen our network collaboration for the development and transfer of new production technology.

A.v. Schoonhoven
Coordinator, Bean Program

Introduction

The dry or common bean *(Phaseolus vulgaris* L.*)* is an important protein and carbohydrate source in human diets in Latin America, where middle- and low-income families often cannot afford sufficient animal protein. Traditionally, beans have comprised as much as 10 percent by weight of diets in the region (Bressani, 1972), but per capita consumption is falling as production increases lag behind population growth rates (Sanders and Alvarez, 1978). Increased production is urgently needed to maintain or increase the affordable protein supply, especially to lower income groups.

What strategy should be employed to increase overall production? Beans are predominantly a subsistence crop produced mostly by small farmers with traditional cultural practices (Silva *et al.,* 1972; Alvarado and Sanders, unpublished). They usually are not adequately fertilized or protected from diseases and insects. Finally, they have received only limited support from national research programs (Roberts, 1970; Hernandez-Bravo, 1973; Pinchinat, 1973). Therefore, increased production and productivity should be achieved by developing technology based on low inputs to meet the needs of current producers.

Roberts (1970) reviewed grain legume yields throughout the world and concluded that multidisciplinary grain legume research programs should be established in the international agricultural research centers. He suggested CIAT become the center for bean *(P. vulgaris)* research. An integrated bean research program was initiated in 1973, although some CIAT staff members had worked on beans prior to that time.

The Technical Advisory Committee (TAC) of the Consultative Group for International Agricultural Research (CGIAR) has given CIAT's Bean Program worldwide responsibility for research on increased bean production. The Program's mandate is to coordinate a collaborative research network for beans, principally in Latin America, and also in Eastern Africa and other major bean production areas of the tropics. CIAT is recognized by the International Board for Plant Genetic Resources (IBPGR) as the world center for management of *Phaseolus* germplasm.

This publication deals with dry bean production and consumption trends, systems of cultivation, and yield constraints in Latin America and, to a lesser extent, in Africa. It also reviews the development of CIAT's bean team, describes its objectives and research priorities, and discusses program achievements. Finally, it outlines future research activities and goals.

Production and Consumption of Dry Beans

The United Nations' Food and Agriculture Organization (FAO) has estimated world bean production at 14.4 million tons annually, during 1977-79. Latin America was the most important production zone with 4.0 million ton/year, approximately 30 percent of the total. Eastern Africa, the second most important zone in the tropics, produced an average of 0.8 million ton/year. Other important bean- producing countries are China and India, according to the FAO. In Asia most of the principal bean types have now been reclassified as *Vigna* sp.

In the last decade in Latin America bean production growth has been substantially below the population growth rate (Sanders and Alvarez, 1978). The annual production increase of 1.2 percent resulted from expanding the area about 1.3 percent annually, since yields have been decreasing (-0.16%). Bean production has lagged substantially behind the 2.7 percent annual growth in population.

While Brazil and Mexico produced almost 78 percent of the region's dry beans, their long-term total production has increased relatively little. Significant production increases were reported, however, in Argentina, Colombia, El Salvador and Guatemala (Table 1). Argentina increased her bean production from 32,000 tons in 1964-66 to 194,000 in 1977-79.

The sharp production gain and consequent increase in Argentine exports made Latin America a net exporter of grain legumes by the mid-seventies. Nevertheless, Brazil, Cuba and Venezuela have imported heavily in recent years and their total imports reached almost 238,000 t annually in 1976-78. Total imports of grain legumes by these traditional importers increased 110 percent, from 159,000 to 334,000 tons, during the period 1963-65 to 1976-78. Despite the rapid increase in imports, per capita consumption of grain legumes declined over the region from 16.8 to 13.3 kg/year.

Table 1. Bean[1] production and yields and per capita consumption of dry legumes in Latin America (1963-65 to 1977-79).

Country	Bean Production ('000 tons)		Dry bean yields (kg/ha)		Estimated per capita comsuption of dry legumes	
	1964-66	1977-79	1964-66	1977-79	1963-65	1976-78
Brazil	2130	2222	655	500	26.6	20.1
Mexico	917	922	431	578	22.9	12.6
Argentina	32	194	1019	1026	3.0	2.9
Colombia	39	74	542	656	5.2	4.9
Chile	87	113	1241	1072	7.3	8.1
Peru	46	59	920	794	9.4	6.2
Haiti	41	34	-	358	10.6	18.9
Paraguay	30	66	-	775	12.9	24.3
Guatemala	44	78	651	586	13.7	13.5
Ecuador	28	29	477	545	13.3	6.4
Dominican Republic	25	37	658	825	15.4	12.8
Venezuela	43	34	427	506	8.4	9.8
Nicaragua	39	49	942	740	26.8	23.8
Honduras	50	25	676	435	14.3	15.9
El Salvador	15	40	631	766	10.7	10.1
Cuba	25	25	-	714	11.8	13.5
Bolivia	14	2	-	800	2.5	2.8
Costa Rica	19	12	316	527	11.2	6.8
Panama	6	3	-	257	8.7	5.4
Uruguay	3	3	-	568	3.6	2.3
Latin America[2]	3635	4023	576	554	16.8	13.3

Source: Modified from Sanders and Alvarez, 1978.

[1] Other legumes (i.e cowpeas, pigeon peas, etc.) are included. Soybeans and groundnuts are excluded.

[2] Includes data from some other countries whose shares of total production were very small.

Yields and the rate of yield improvement were less than those obtained with cereal grains and soybeans over the same years (FAO, 1963-1975). Yields over the region have remained low, compared, for example, to the U.S.A. average of 1 509 kg/ha. Yields in Latin America have declined from 580 to 559 kg/ha, an annual rate of -0.16 percent from 1962 to 1979.

These statistics reflect a complex production situation. In Argentina and Chile, two of the major bean exporters, production is concentrated on relatively large holdings receiving high levels of inputs (Hernandez-Bravo, 1973; INTA, 1977). Although other Latin American countries possess limited areas where large bean farms predominate, most beans are produced on smaller holdings, often on slopping land of low fertility. Bean producing farms in El Salvador and Haiti average less than one hectare in size (Aguirre and Miranda, 1973; Scobie *et al.*, 1974). Under these circumstances the tendency is toward multiple cropping systems (Junqueira *et al.*, 1972; Pinchinat, 1977) using minimal inputs (Bazan, 1975; Ruiz de Londoño *et al.*, 1978). Beans have increasingly been displaced from the more fertile, mechanizable lands by crops such as sorghum and soybeans which have a more stable production and marketing situation.

Bean seed color and size preferences vary widely (Moh, 1971; Flores *et al.*, 1973; Scobie *et al.*, 1974) and complicate the production and consumption pictures (see columns 4 and 5 of Table 3). Black-seeded cultivars have outyielded those of other seed colors (Moh, 1971; CIAT, 1978). However, in many countries black beans either are not consumed or receive a substantial price discount.

Bean production increases of almost 3 percent annually are needed to match population growth rates. Even if production were to increase 6 percent annually, an initial price decline would be partially offset by increased consumption in middle- and low-income families (Pinstrup-Andersen *et al.*, 1976). In contrast to the "green revolution" crops, rice and wheat, bean yield increases of that magnitude would need to occur in a predominantly subsistence crop which is rarely irrigated, fertilized or protected from pests, which is produced under many farming systems and in which grain color and size preferences will slow the rate of development and acceptance of improved cultivars.

Production Problems of Beans

Under experimental conditions, bush bean yields as high as 5.0 t/ha have been reported (Cartee and Hank, 1974; CIAT, 1975a), and climbing beans on artificial support systems have yielded even higher (CIAT, 1976). The gap, however, between experimental yields and mean farm yields (less than 600 kg/ha in association) is huge. A review of the factors responsible for this gap is essential in devising a strategy for increasing yields.

The literature and farm surveys clearly indicate that diseases and pests are the major factors responsible for extremely low yields. More than 250 pathogens and 450 insects attack *P. vulgaris*. Several of these are widely distributed and can reduce yields substantially (Wellman,1969; Ruppel and Idrobo, 1962; Vieira *et al.*, 1971; Mancia and Cortez, 1975). An attempt was made by researchers to identify major bean diseases in Latin America. Bean common mosaic virus (BCMV), rust, anthracnose, angular leaf spot, powdery mildew and common bacterial blight were, in that order, considered major diseases in South America (Gutierrez *et al.*, 1975).

Various regional surveys of production losses support these overall priority estimates (Echandi, 1966; Schieber, 1970; Costa, 1972; Crispin and Campos, 1976). Losses to BCMV can range from 53-96 percent (Laborde, 1967; Costa, 1972; Crispin, 1974; Hampton, 1975; Crispin and Campos, 1976); to bean rust from 18-82 percent (Carrijo, 1975; CIAT, 1975a); and to anthracnose, as much as 97 percent (CIAT, 1975a).

Several diseases are important under specific regional or climatic conditions. As cotton and soybean production expanded in Brazil, populations of *Bemesia tabaci*, the bean golden mosaic virus (BGMV) vector, increased. This virus has become a serious problem in many regions of Southern Brazil, as it already was in Central America (Gamez, 1971; Costa, 1972; Costa and Cupertino, 1976). In warm, humid regions web blight can devastate production (Crispin and Gallegos, 1963; Echandi, 1966 and 1976). In cooler regions where anthracnose is important, various local fungal diseases, root rots and halo blight are often important as well (Cardona and Skiles, 1954; Costa, 1972; Crispin and Campos, 1976; Shands *et al.*, 1964).

In Eastern Africa, anthracnose and halo blight are the principal pathogens (Leakey, 1970; Kenyan Ministry of Agriculture, 1975). Other diseases such as rust, BCMV, Southern blight, white mold, Fusarium root rot, Cercospora, Alternaria, Ascochyta, angular leaf spot and bean scab are also important in Africa (Rheenen, 1978; Edje and Mughogho, 1974; CIAT. Regional Workshop on Potential for Field Beans in Eastern Africa, 1981). Bean scab so far has not been reported in Latin America.

Although diseases are considered to be more important, insects can also reduce bean yields substantially and losses as high as 94 percent are reported. Leafhoppers *(Empoasca kraemeri)*, chrysomelids and cutworms are important in most Latin American bean production zones (Bonnefil, 1965; Gutierrez *et al.*, 1975). Other insects such as the bean pod weevil *(Apion godmani)* and the Mexican bean beetle *(Epilachna varivestis)* are important in Central America and Mexico (Enkerling, 1957). In Africa, the bean fly *(Ophiomyia* spp.) form the principal production limiting insect pest (Leaky, 1970).

CIAT conducted an in-depth study of bean yield constraints in Colombia to better define production systems and problems. This study was made during 1974 and 1975, when Colombia exported black beans produced in large holdings in the Valle del Cauca and Huila regions. The survey indicated a greater potential productivity in the more fertile Valle del Cauca than in Huila and Nariño. Actual farm yields were 905 and 598 kg/ha, in Valle and Huila respectively. The former region was characterized by large farms while small farms were common in the other two regions. In spite of large expenditures on inputs including fungicides and insecticides (Table 2), disease and insect losses were still high in the large-farm, monoculture region of Valle. The combination of rust, common bacterial blight, angular leaf spot, and leafhoppers reduced yields in Valle del Cauca by 500 kg/ha, or 36 percent. Thus, in the Valle, mechanization, monoculture, high input levels and planting improved black-seeded cultivars such as ICA- Pijao and ICA-Tui still did not increase yields to 1 ton/ha. In Huila and Nariño, input use was much lower and beans were produced principally in association with maize.

Table 2. Characteristics of dry bean production in four regions of Colombia, 1974-75.

	Region			
	Valle del Cauca	Huila	Antioquia	Nariño
Avg. farm size (ha)	48.0	25.2	4.5	4.0
Area in beans (ha)	22.6	4.1	1.5	1.8
Percentage of farms using:				
Irrigation	25	3	0	0
Certified seed	52	7	0	0
Fertilizers	84	24	100	0
Herbicides	32	0	0	0
Insecticides	87	23	33	10
Credit	100	10	42	0
Technical assistance	71	30	8	32
Mixed cropping	0	74	100	95
Machinery	100	44	0	0
Bean yield (kg/ha)	906	683	533	447
Bean equivalent yield[1] (kg/ha)	906	825	723	703

Source: Modified from Ruiz de Londoño et al., 1978.

[1] The Bean equivalent yield is: $Y_B + \frac{P_C Y_C}{P_B} = Y_{B.E.}$; where, Y_B is the bean yield, Y_C is the yield of the other associated crop, $Y_{B.E.}$ is the bean equivalent yield, and $\frac{P_C}{P_B}$ is the associated crop price relative to the bean price (P_B)

The prevalence of diseases in traditional bean production zones implies that new varieties with higher yield potential but lacking the appropriate resistances would confront even larger potential yield losses than those reported here. In summary, the Colombian farm data indicate the prevalence of many serious diseases in the principal bean regions, the importance and difficulty of controlling diseases and insects with chemicals, and the importance of incorporating disease resistance into new higher-yielding cultivars, so they can attain their yield potential.

Based on the studies cited above and several years of work within the Latin American bean network, requirements for disease and insect resistance in varieties for the principal production zones of Latin America have been defined (Table 3). These requirements are always under review as new data and observations become available. The principal disease and insect problems and other important constraints to bean production are discussed more fully in the next section (see also Schwartz and Galvez, 1980).

Diseases

Bean common mosaic virus (BCMV). It has been reported from all bean producing countries in Latin America and Africa (Gamez, 1977; Kulkarni, 1973). Most regionally important varieties, especially nonblack-seeded types are susceptible to the virus. This is transmitted in seed, by aphids, and mechanically. Several strains of the pathogen have been identified in Latin America (Alvarez and Ziver, 1965; Guerra *et al.*, 1971); Gamez, 1973; Drijfhout *et al.*, 1978) including strains which can cause systemic necrosis in some cultivars (Drijfhout, 1975). Two types of resistance to BCMV have been identified; those conditioned by recessive and strain-specific genes or by a dominant "I" gene, which prevents chronic systemic infection (mosaic) and seed transmission of the virus.

Breeders in Latin America have principally utilized the dominant type of resistance (Cafati and Alvarez, 1975). Neither resistance alone may be sufficient for all Latin American conditions. If plants possessing the dominant I gene are infected by a necrosis-inducing strain of BCMV, systemic necrosis and plant death can result. With limited quarantine control in most countries, introduction of new mosaic or necrosis-inducing strains of the virus is a real possibility.

Recently, resistance to all known BCMV strains was identified in germplasm from temperate zones (Drijfhout, 1978). In farm trials in Colombia, virus-free seed of varieties susceptible to BCMV could not substitute for varietal resistance to the virus (CIAT, 1978 and 1979). The Bean Program has therefore given its highest priority to incorporating resistance to BCMV into its new materials.

Table 3. Varietal requirements for principal dry bean production zones in Latin America and Central and Eastern Africa.

Cropping systems	Production zones	Varietal characteristics			Resistances/ Tolerances required[2]		Important varieties grown
		Seed		Growth habits[1]			
		Color	Size		General	Regional	
Monoculture and intercropping	Brazil (Southern and Eastern areas)	Black	Small	II and III	Rust, Common bacterial blight, Anthracnose, Angular leaf spot, *Empoasca*	Bean golden mosaic virus, *Apion*, Low P	Rio Tibagi, Iguacu, Costa Rica, Tayhu, Rico 23
	Some areas of Costa Rica, El Salvador and Honduras	"	"	II and III			Turrialbas, Pascuaral, Pavamor, Porrillos
	Cuba	"	"	II			ICA-Pijao, ICA-Tui, Porrillo Sintético
	Guatemala	"	"	II, III and IV			Compuesto Chimalteca, San Martin, Pecho Amarillo, Suchitan
	Mexico (Gulf, Southern Pacific and Yucatan Peninsula areas)	"	"	II			Jamapa
	Venezuela	"	"	II and III			Tacarigua, Coche, Cubagua
Monoculture and intercropping	Brazil (Southeastern and West Central areas)	Brown, creme and pink	Small	II and III	Rust, Common bacterial blight, Anthracnose, Angular leaf spot, *Empoasca*	Bean golden mosaic virus, Low P	Mulatinho, Aroana, Carioca, Roxao, Roxinha
Monoculture	Brazil (Northeastern area)	Creme	Small	II and III	Rust, *Empoasca*, Common bacterial blight	Drought	Mulatinho, IPA47-19, Favinha, Chita Fina
Intercropping	Nicaragua and some areas of Costa Rica, El Salvador and Honduras	Red	Small	II, III and IV	Rust, Common bacterial blight, *Empoasca*, Angular leaf spot	Bean golden mosaic virus, *Apion*, Web blight	Nahuizalco, Zamorano, Mexico 80, Honduras 46
Monoculture and intercropping	Belize, Cuba, Dom. Republic, Haiti, Panama and Puerto Rico	Red and red-mottled	Medium and large	I and III	Rust, Anthracnose, Angular leaf spot, *Empoasca*	Ascochyta, Gray spot, Mildew, Bean fly	Pompadours, Red Kidney, Cueto, Cajalas, Decayette
	Intermediate and high Andean slopes of Colombia, Ecuador and Peru	Red, and, red-mottled, white and yellow	Medium and large	I, II, III and IV			Calima, Andino, Catio, Radical, Sangre de Toro, Cargamanto, Bolones, Canarios, Mantequilla, Falelo
	Central and Eastern Africa: Burundi, Kenya, Malawi, Rwanda, Tanzania and Uganda	Red, red-mottled and brown	Medium and large	I, II and III			Rose Coco, Canadian Wonder, Mwezi Moja
Monoculture and intercropping	Argentina and Chile	White	Small and large	I, II and III	Rust, Common bacterial blight, *Empoasca*	Bean yellow mosaic virus, *Epinotia*, Drought	Alubias, Cristal, Arroz
	Coastal areas of Ecuador and Peru	White, creme and yellow	Small, medium and large	I, II and III	—		Canarios, Panamitos, Bayos, Caballeros
	Mexico (North and Central Pacific, Bajio and Central Plateau areas)	Creme, yellow and mottled	Medium	I, II, III and IV			Azufrados, Canarios, Cacahuete, Flor de Mayo, Bayos

[1] For description of growth habits, see Table 6

[2] Bean common mosaic virus is considered a universal problem and all advanced lines leaving the CIAT Bean Program are resistant to this virus.

Rust. Bean rust *(Uromyces phaseoli)* is endemic to Latin America and may be the most important bean disease in subtropical regions up to elevations of 2500 m above sea level. Many races have been identified (Echandi, 1966; Christen and Echandi 1967; Netto *et al.*, 1969; Augustin and Costa, 1971a; Costa, 1972). Major shifts in race prevalence have been observed between seasons (Antunes, cited by Costa, 1972) and with the introduction of new cultivars (Augustin and Costa, 1971a).

Many rust-resistant cultivars exist (Costa, 1972; Coyne and Schuster, 1975) but few retain their resistance over long periods of time or in all regions (CIAT, 1979). Stable resistance to rust is one of the highest priorities of the Bean Program. Basic studies are needed on alternative control strategies, such as gene pyramiding, development of more stable resistance and cultural practices for reducing disease incidence.

Anthracnose *(Colletotrichum lindemuthianum)*. It is a major pathogen in Argentina, Brazil, Mexico, and high altitude regions in Central America, the Andean Zone countries and Eastern Africa. One hundred percent field infection can occur (Shands *et al.*, 1964; Augustin and Costa, 1971b; Araujo, 1973; Echandi, 1976; INTA, 1977; Gutierrez *et al.*, 1975). While race differentials and nomenclature remain to be standardized, 10 apparently distinct races of anthracnose have been identified.

The cultivar Cornell 49-242 is resistant to important races in Latin America (Oliari *et al.*, 1973) and has been used in breeding for resistance. New and distinct sources identified by Bannerot *et al.* (1971), Fouilloux (1976) carry resistance against additional races (Kruger *et al.*, 1977), some against all known races (Drijfhout, pers. comm.). Resistance to anthracnose is a requisite for all new materials the Bean Program develops for cooler production zones.

Angular leaf spot *(Isariopsis griseola)*. This is perhaps the most underrated of the major bean diseases. Despite intensive efforts to develop control methods in Colombia (Barros *et al.*, 1957; Bastidas, 1977), the disease continues to cause appreciable losses there and in other countries, partly because it can be seed-transmitted (Diaz *et al.*, 1965; Crispin and Campos, 1976; Ruiz de Londoño *et al.*, 1978). Brock

(1951), Olave (1958) and Santos-Filho *et al.* (1976) have identified sources of resistance to this disease with resistance controlled by a single recessive gene. Possible race relationships for this pathogen must still be studied. The Program is developing resistance to angular leaf spot in specific materials.

Common bacterial blight *(Xanthomonas phaseoli).* It is one of the most imortant disease pathogens due to its wide occurrence and seed transmission. Moreover, it is difficult to control chemically or through varietal resistance. Resistance has been identified in GN-Nebraska No. 1 Sel 27 and PI 207 262 and appears to be quantitatively inherited with different genes controlling resistance in each cultivar. The narrow adaptation of the above two cultivars (CIAT, 1977) will necessitate extensive breeding efforts to incorporate resistance into tropically adapted cultivars and to pyramid resistance levels. Resistance in GN-Nebraska No. 1 Sel 27 was derived from interspecific hybridization with blight-resistant *P. acutifolius* and more such crossing should be done. Incorporation of common bacterial blight in materials for the tropical production zones is one of the priorities of the Program.

Insect Pests

Leafhopper. Of the insects attacking beans, the leafhopper *(Empoasca kraemeri)* is considered the most widespread and injurious (Bonnefil, 1965; Langlitz, 1966; Costa and Rosetto, 1972; Gutierrez *et al.*, 1975). Gutierrez *et al.* (1975) reported significant damage by this insect in 11 of 12 Latin American countries surveyed. Yield losses of up to 96 percent have been reported (Diaz-Castro, 1971; Miranda, 1971). Damage is generally greatest under dry conditions.

While intermediate levels of tolerance have been identified (Wolfenbarger and Sleesman, 1961) current control methods usually emphasize insecticides (Costa and Rossetto, 1972). The leafhopper is the only insect to which the Program has given priority to incorporate resistance into improved lines.

Bean pod weevil *(Apion godmani)* is major bean pest in Mexico, Guatemala, El Salvador, Honduras, and Nicaragua (McKelvey *et al.*, 1947; Enkerling, 1957; Mancia, 1973a) with pod infestation ranging from 20-95 percent (Enkerling, 1957; Diaz, 1970; Mancia, 1973a).

While resistant varieties have been identified (Guevara, 1957 and 1969; Mancia, 1973b), present control recommendations depend primarily upon insecticides (Diaz, 1970; Mancia, 1973a). Resistance to *Apion* is being develop in new lines intended for Central America.

Mexican bean beetle *(Epilachna varivestis).* It is a major problem in Mexico, Guatemala and El Salvador, where yield losses of up to 75 percent are reported (Paz *et al.*, 1975). Existence of resistant cultivars has been reported (Campbell and Brett, 1966; Garcia and Sosa, 1973; Raina *et al.*, 1978).

Storage insects. . The principal insects attacking stored beans are two bruchids, *Acanthoscelides obtectus* and *Zabrotes subfasciatus.* Both are common throughout Latin America but direct loss estimates are surprisingly low (Schoonhoven, 1976). However, these insects may be indirectly more important as they force the rapid sale of beans after harvest, thereby contributing to post-harvest price collapses (CIAT, 1977).

Nematodes. Nematodes have been studied relatively little in Latin America but are important in Brazil, Chile, Mexico and Peru (Costa, 1972; Crispin and Campos, 1976; Jimenez, 1976). Important genera in Colombia include *Helicotylenchus, Pratylenchus* and *Meloidogyne.* Weeds, especially *Bidens pilosa,* increased nematode populations according to studies by Riedel (CIAT, 1978).

Given the major disease and insect problems mentioned, intensive breeding efforts are needed to incorporate identified resistance genes into locally important varieties. Genetically improved varieties, such as Diacol-Calima, ICA-Pijao, and Canario Divex are available in some countries and have significantly improved yields, e.g., in Colombia, Brazil and Mexico (Orozco *et al.*, 1964; Vieira, 1970, 1974 and 1977; Cafati and Alvarez, 1975; Lopez and Andrade, 1975; Bastidas, 1977). However, most commercial varieties such as Flor de Mayo, Jamapa and Canario 101 (Mexico), Carioca and Rio Tibagi (Brazil), Alubia and Caballero (Argentina), Tacarigua (Venezuela), Pompadour (Dominican Republic), Rojo de Seda and Zamorano (Central America) and the Porrillos are mass or individual plant selections obtained from land race cultivars (Crispin, 1968; Ortega and Barrios, 1972; INTA, 1977); they are susceptible to most of the important diseases and insects.

Phosphorus and Nitrogen Deficiencies

Besides diseases and pests, agronomic constraints, particularly problems of phosphorus or nitrogen deficiency and soil acidity contribute to poor bean yields. Analyses of 110 Central American soils showed 20 percent had a pH of less than 6.0 (Muller *et al.,* 1968), 66 percent were highly deficient in phosphorus (Fassbender *et al.,* 1968) and 75 percent, deficient in nitrogen (Díaz-Romeu *et al.,* 1970).

Central American bean fertilization trials, reviewed by Fassbender (1967) and Bazan (1975), showed widespread responses to nitrogen and phosphorus but not to potassium. Malavolta (1972) reviewed 232 bean fertilization trials in eight Brazilian states and reported responses to nitrogen (67 times), phosphorus (103), potassium (15), lime (31), and micronutrient combinations (17). Aluminum (Buol *et al.,* 1975) and manganese toxicities associated with the low soil pH (Dobereiner, 1966) and molybdenum deficiency (Franco, 1977) complicate fertilizer recommendations. The observed large genetic variation in phosphorus requirements among bean cultivars, especially in those from Brazil (Whiteaker, 1975; CIAT, 1978 and 1979) are being exploited as a method to partially overcome this soil constraint.

Given the low nitrogen status of many soils it is unfortunate that many commercial cultivars of *P. vulgaris* have proved weak in symbiotic nitrogen fixation. Yield increases following inoculation have been reported (reviewed by Graham and Halliday, 1977) but inoculation failure is common. Currently, less than 1 percent of the bean seed planted in Brazil receives inoculation (Araujo, 1974). By exploiting the *Rhizobium* strain x bean cultivar interaction, the Bean Program attempts to reduce dependence on nitrogen fertilization.

Seed Quality

Major bean pathogens such as BCMV, anthracnose, angular leaf spot and common bacterial blight are seed-transmitted. Although beans have their center of origin in Latin America, the ability of seed transmission of most important diseases may be a major factor accounting for similar disease problems in Africa.

In the U.S.A., certified seed is produced in relatively dry areas (e.g., Idaho) with little disease pressure, to meet stringent quality standards (Copeland *et al.,* 1975). Over an eight-year period in Michigan, bacterial blight incidence on farms not using pathogen-free seed was 3 to 10 times as high as that on farms utilizing such seed. Latin American bean-producing countries generally lack effective systems of bean seed production and quality control. In both Colombia and Brazil, for example, fewer than 4 percent of the farmers use certified seed (Silva *et al.,* 1972; Walder *et al.,* 1977; Bastidas, pers. comm.).

In Minas Gerais, Brazil, 59 percent of 338 farmers surveyed resowed harvested seed for between two and five years, while only 16 percent used pure line seed (Walder *et al.,* 1977). In a Costa Rican study, Sanchez and Pinchinat (1974) observed an average germination of 68 percent for farmers' seed. These studies indicate the importance of producing high-quality seed, and the Bean Program and CIAT's Seed Unit give great importance to improving seed production in Latin America.

Drought

Some degree of water stress is common in most bean producing areas (CIAT, 1979). However, it is endemic in Northeastern Brazil and Coastal Peru and Ecuador; beans are seldom produced under irrigation in these areas. Moderate levels of tolerance to drought have been identified but it may be difficult to obtain materials resistant to extended dry periods. Short-season varieties may be needed for certain regions. Experience has shown that farmers have sought to compromise between disease presence and drought risk by planting beans so that they mature at the end of the rainy season.

Other Agronomic Constraints

In Latin America beans are often grown in association principally with maize, but also with cassava, coffee, potatoes and other crops (Moreno *et al.,* 1973; Andrade *et al.,* 1974; Ruiz de Londoño *et al.,* 1978). Many different cropping systems exist. Approximately 80 percent of the bean area in Latin America is sown in association (Gutierrez *et al.,* 1975), and 75-90 percent of the area in Africa (Leakey, 1970). Associated culture— the growth of two or more crop species together for part of their life cycles—does lower yields of beans and the companion crop (Francis *et al.,* 1977; Ruiz de Londoño *et al.,* 1978). However, there may be advantages to association such as reduced pest incidence, erosion control and reduced economic risk

(Lepiz, 1971; Moreno *et al.,* 1973; Andrade *et al.,* 1974; Soria *et al.,* 1975; Desir and Pinchinat, 1976). While experimental yields of about 2 ton/ha of beans with 5 ton/ha of maize have been reported (Desir and Pinchinat, 1976), yields are generally much less (Krutman, 1968; Santa Cecilia and Vieira, 1977). Agronomic research is complicated in farming systems by the large number of variables, including densities of maize and beans, time of planting, fertilization, weed control and compatibility of cultivars.

Relay cropping—where crops share the same area for part of their growth cycle, but at different stages of development—is common with beans and maize. In Central America beans are planted near the end of the rainy season and must face diminishing soil moisture during flowering and pod formation (García and Zandstra, 1977). Development of later-maturing maize populations for these regions would aggravate the problem of raising bean yields (García and Zandstra, 1977).

In summary, beans in Latin America are produced mostly by small farmers as a cash crop. Due to uncertainty of production from high disease pressure or drought, farmers utilize few inputs; consequently, bean supplies and prices fluctuate greatly from year to year. On the other hand, increasing production stability by increasing environmental stress resistance enables farmers to use inputs, and beans may move back into the better lands. The low-input philosophy of the Bean Program is directed to achieving these objectives, although the use of inputs is always expected to increase production.

Objectives and Strategies of the Bean Program

The Bean Program has the major objective of developing, in collaboration with national programs, technology that can lead to increased productivity of field beans. The Program formulated its first strategies following a 1973 conference on the potential of field beans in Latin America (CIAT, 1973). Literature and economic surveys, and visits to and from national programs are continually used to reevaluate and modify strategies. The Program's principal activities for attaining its objective are: (1) germplasm improvement; (2) development and validation of improved agronomic practices; (3) training of national program scientists; and (4) international collaboration.

The Bean Program plans to achieve its overall objective by concentrating upon germplasm improvement. Emphasis is upon development of scale-neutral production technology with bias to the needs of the small farmer. This is being achieved by development of germplasm resistant or tolerant to diseases and insect pests instead of making chemical control recommendations. Reduced dependence on chemical fertilizers and tolerance to water stress are sought; no research is done on practices such as mechanization or irrigation. Work on improvement of climbing bean technology is directed exclusively towards small-scale farmers. The Program emphasis will stay on Latin America but outreach activities will include Eastern Africa.

Development efforts are limited to the common bean, *P. vulgaris*. Research on related species such as the scarlet runner bean *(P. coccineus)* and the tepary bean *(P. acutifolius)* is limited to their contribution to improving the common bean through interspecific hybridization. The lima bean *(P. lunatus)* collection at CIAT will be evaluated, documented and maintained for national program use but no breeding work will be undertaken.

No major effort is made to adapt beans to areas outside their current production zones, such as the hot humid lowlands, or the highly acid, infertile soils. Other legumes have comparative advantages in adaptation to these areas, while the cost and time involved to adapt beans to these areas are prohibitive.

Germplasm Improvement

The Bean Program places its major emphasis upon improving germplasm. This encompasses the collection, maintenance and evaluation of germplasm and the development and distribution of genetically improved bean germplasm.

Collection, maintenance and evaluation of bean germplasm. The CIAT germplasm bank currently stores around 30,000 accessions of *Phaseolus* spp., primarily *P. vulgaris,* obtained from more than 20 countries. In collaboration with national institutions and the IBPGR, additional germplasm is periodically collected from those areas where numbers or diversity of materials are lacking. CIAT's Genetic Resources Unit is primarily responsible for the maintenance, morphological characterization and distribution of germplasm bank accessions.

Staff of the Bean Program actively participate in evaluating accessions for resistance to various diseases and insect pests, for plant architecture and yield potential, and for their response to climatic and edaphic constraints. A common procedure is to screen accessions for desired variability in observation nurseries both at CIAT-Palmira and Popayan. Hill plots or small row plots are used to accommodate large numbers of entries. This is done especially for accessions which have not been screened before or when a new problem arises for which desired variability is needed.

Accessions which appear promising are normally reevaluated for the same character and are entered in the First Uniform Screening Trial (VEF) (Fig. 1) and tested for additional factors if they are also homozygous resistant to BCMV.

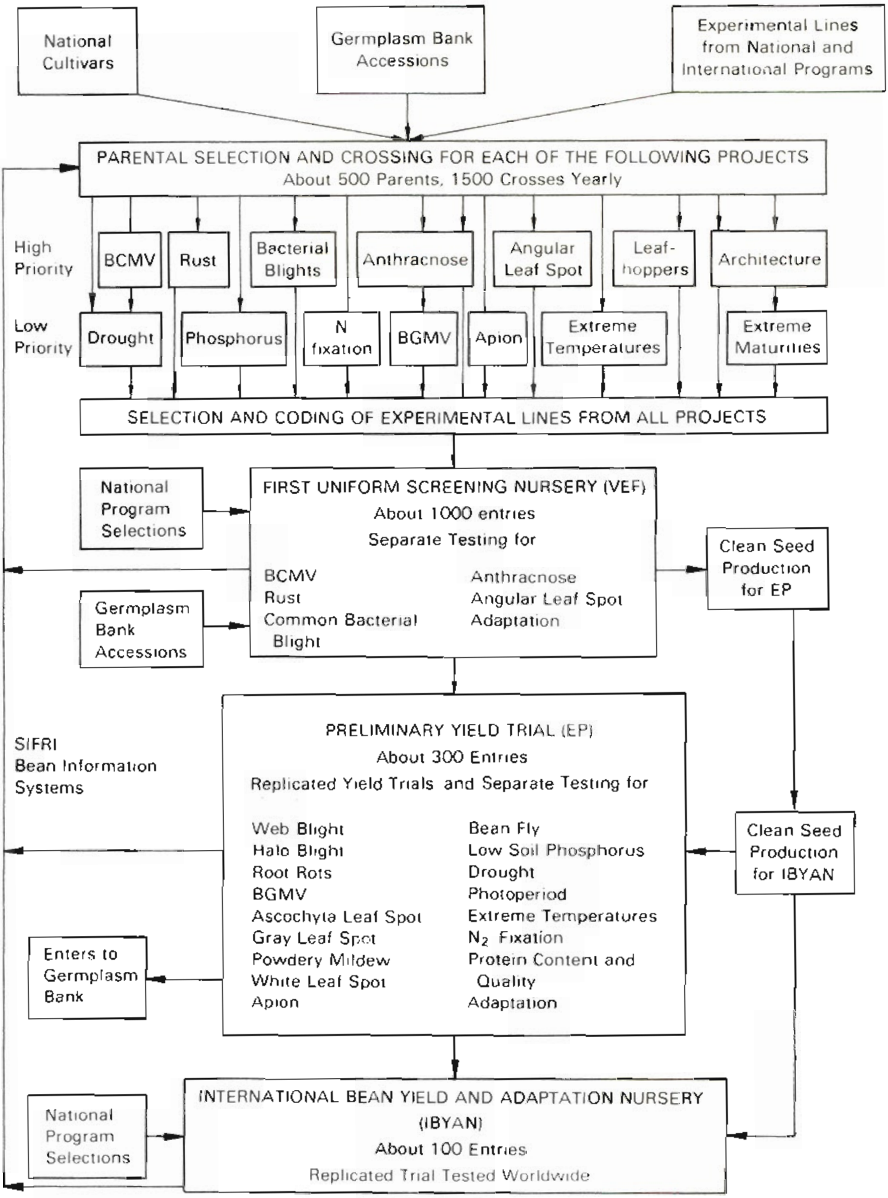

Figure 1. *Stepwise germplasm development and evaluation scheme used by the CIAT's Bean Program.*

Moreover, selected materials may be directly utilized as parents in hybridization and/or entered in international screening nurseries. This system assures the continuous flow of desirable variability from the bank to germplasm improvement projects.

Development of genetically improved germplasm. The principal short-term goal of the Bean Program is to achieve yield gains under farmers' conditions through breeding for resistance to diseases and insect pests. Simultaneously, research is being done to increase tolerance to stress environments and to improve plant architectural characteristics. Physiological traits possibly leading to improved yield potential have been identified in beans, and the search for these traits continues. They include stem strength, tap root, differences in maturity, erect branches and narrow leaves. After incorporation into materials of good agronomic background, their true value can be determined.

Incorporating resistance to BCMV, rust, anthracnose, angular leaf spot, common bacterial blight and leafhoppers into agronomically and commercially acceptable lines is the primary objetive. The immediate goal is to consolidate resistance to multiple factors in materials with yield potential equal to or higher than present cultivars. They must fit into actual production systems and meet seed size and color preferences of consumers. Not all combinations of resistances are necessary in all materials (Table 3, pag. 17). Resistance to common bacterial blight is not very important in beans for the Andean highlands. Anthracnose resistance is not necessary for many warm production regions in Central America, Coastal Peru, Ecuador and Chile.

Genetic variation for tolerance of beans to stress environments, principally drought and low soil phosphorus, is sought. Architectural traits—stem strength to prevent lodging and disease accumulation due to soil contact of pods, and plant height, to increase numbers of pod-carrying internodes and photosynthetic capacity—are improved simultaneously. Breeding for improved protein content and quality and cooking properties is presently of low priority. Seed color and size of advanced materials must satisfy the requirements of consumers in the different regions.

Two breeders in the Program dedicate full time to bush beans, and one, to climbing beans. One bush bean breeder concentrates on breeding for increased resistance levels to diseases and insects prevalent in warm climates. The other breeder works on improving yield potential through better plant architecture, increasing stress tolerance to climatic and edaphic factors, and improving resistance to diseases prevalent in cooler regions (Table 4).

Table 4. Bean improvement breeding projects of the CIAT Bean Program.

Major program	Objective for improvement
Bush Bean Breeding (I)	1. Resistance to bean common mosaic virus (including multiple resistance genes)
	2. Resistance to rust and stability of rust resistance
	3. Tolerance to leafhoppers *(Empoasca kraemeri)*
	4. Resistance to common bacterial blight
	5. Tolerance to bean golden mosaic virus
	6. Resistance to bean pod weevil *(Apion godmani)*
	7. Biological fixation of N
	8. Selected national cultivars, for each of the above factors
Bush Bean Breeding (II)	1. Plant architecture and yield potential
	2. Resistance to anthracnose
	3. Resistance to angular leaf spot
	4. Tolerance to low soil P
	5. Tolerance to drought
	6. Range in maturity (early or late)
	7. Tolerance to extreme temperatures
	8. Selected national cultivars, for each of the above factors
Climbing Bean Breeding	1. Small-seeded cultivars (red and black) for resistance to bean common mosaic virus, leafhoppers, white spot and Ascochyta (Type III b and IVa)[1].
	2. Medium-seeded cultivars (yellow and brown) for resistance to bean common mosaic virus, angular leaf spot, rust and leafhoppers (Type III b and IVa).
	3. Large-seeded cultivars of various colors for resistance to bean common mosaic virus, anthracnose, rust, leafhoppers and Ascochyta (Types IVa and IVb).

[1] For description of growth habits, see Table 6, page 35.

For the genetic improvement of climbing beans, the same principles and priorities apply as for bush beans. Although no accurate data exist on the relative importance of climbing versus bush beans, one-third of the total breeding effort for climbers is estimated to be above the relative importance of this type, again indicating the Bean Program's bias towards small producers. As there is a variety by cropping system interaction for yields of climbing bean varieties, genetic improvement evaluations are done in the cropping system the material is intended for, that is, in direct association or in relay systems with maize. For direct association, a vigorous bean type is sought to provide an optimal yield combination in both maize and beans. For relay cropping, too vigorous a bean variety would cause maize lodging. Major aspects of germplasm improvement activities are described below.

Parental selection and hybridization

Parental sources include national cultivars, gèrmplasm bank accessions, introductions and experimental lines or selections in various stages of development and evaluation. The germplasm development and evaluation scheme used by the Bean Program is shown in Figure 1. Before initiating each recombination cycle, the list of parents used in crossing is updated, based upon information available from previous nurseries, progeny performance, specific requests of collaborators, and Program directions.

In collaboration with CIAT's Data Services Unit, a computerized information system (SIFRI; see Fig. 1) is utilized to document the handling and evaluation of germplasm bank accessions, parents, crosses and selections. This helps avoid duplication of breeding efforts, assists in progeny management and facilitates responding to outside requests.

Special attention is being given to rapidly improve widely grown cultivars, such as Jamapa, Canarios, Flor de Mayo, Zamorano, Pompadour, Diacol-Calima, Cargamanto, Sangre de Toro, Favinha, Mulatinho, Roxinhos, Iguacu, Alubia, and others. The basic adaptive features, grain and plant types of these cultivars are reselected while crossing them to: (a) sources of resistance to important disease and insect pests limiting their specific regional production potential; (b) similarly, to sources of tolerance to adverse climatic and edaphic factors; and, (c) better plant architectural types to improve their yield potential.

Germplasm improvement activities are divided into projects (Fig. 1 and Table 4) in which desired variability is recombined and built up further. When improving a particular character, parental combinations are sought which enhance and stabilize its expression as well as combine it with other desirable traits. For example, for common mosaic virus, sources of resistance to different strains of this virus are being crossed with tropically adapted parents possessing agronomic value and resistance to insects and other diseases. In general, parents are selected which combine overall performance with specific characteristcs that complement or contrast with those of the other parent.

Single but especially three-way crosses are commonly made. A limited number of backcrosses are made to improve selected national cultivars. In some projects selected F_3 and F_4 families are utilized for early generation intermating and recurrent selection.

Crosses are made manually in screenhouses or field-crossing blocks at CIAT-Palmira or Popayan. The latter site is primarily used for materials which are poorly adapted at Palmira. The feasibility of utilizing male sterility and extrose stigma characters is being studied as a method for population improvement. The number of crosses in different projects takes into account Program priorities, availability of screening facilities and breeding methods employed.

Management of populations, screening and selection

All segregating populations and early-generation families are grouped together and managed separately for each project until their promising selections enter the First Uniform Nursery (VEF). For example, all crosses made for rust resistance are planted season after season in the rust evaluation nursery for screening, selecting and purifying until lines breeding true for their resistance are identified. Similar procedures apply for BCMV, leafhopper, common bacterial blight, and anthracnose nurseries. For simultaneous improvement or incorporation of two or more characters, complementary parents possessing multiple desirable traits are crossed. Early generations are screened in one of the three following manners:

1. **Simultaneously,** when and if inoculating, screening and selecting techniques are compatible, e.g., for anthracnose and angular leaf spot, common bacterial blight and rust. In some cases, several diseases are evaluated in the same nursery, in other cases, separate nurseries are needed for each disease or pest.

2. **Alternately,** e.g., for anthracnose and low soil phosphorus tolerance, or anthracnose and leafhoppers in which the F_2 populations are first screened for resistance to anthracnose in Popayan and survivors evaluated at CIAT- Quilichao for low soil phosphorus or at CIAT- Palmira for leafhoppers. The sequential testing continues until desired recombinants are identified.

3. **Divergently,** in which the population is either divided for screening or first screened for the primary character or the character with high heritability—most frequently disease resistance—and then seed of selected plants is split. One part is used for its progeny confirmation test and the remainder is used for evaluation against the additional factor(s). The sequence is repeated until true—breeding recombinations are selected.

All phases of germplasm development and evaluation are an integrated team activity. While several team members work closely in the initial stages of germplasm improvement in a particular project, all participate in evaluating advanced selections from any project or source entered in the uniform screening nurseries.

Screening and selection activities are conducted in a few locations (mainly CIAT-Palmira and Popayan) which are representative of major ecological bean production zones (Table 5). Nearly 80 percent of the bean production zones show average growing season temperatures which fall between those of the two principal testing sites—CIAT-Palmira and Popayan (Fig. 2). CIAT-Quilichao is used primarily to screen for low soil phosphorus and biological nitrogen fixation. The La Selva and Obonuco substations of the Instituto Colombiano Agropecuario (ICA) are principally used for climbing beans and associated technology such as inoculation in relay or association with maize. For climbing beans, in addition to the above factors, the F_3 and subsequent segregating populations are screened directly in the appropriate cropping system (relay or association). Selected progenies and yield trials are subsequently evaluated in associated and/or relay cropping systems with regionally predominant maize cultivars.

Screening for production constraints not occurring in Colombia, including BGMV, *Apion* and the bean fly, requires that crosses be made and verified at CIAT-Palmira before seed of segregating populations can be sent to collaborators for screening and selection. Seed of selected progenies is brought back to CIAT to initiate the next cycle of the improvement process.

Table 5. Climatic and edaphic characteristics for major research sites of the CIAT Bean Program[1].

Site	Altitude (masl)	Mean temperature (°C)	Rainfall (mm/year)	Organic matter (%)	pH	P content, Bray II (ppm)	Soil texture
Principal:							
CIAT-Palmira, Valle del Cauca	1000	23.7	1000	6.8	6.9	46.3	Clay
Popayan, Cauca	1850	17,5	1877	32.0	5.1	1.5	Clay-loam
Secondary:							
CIAT-Quilichao, Cauca	1052	24.8	1845	4.1	4.5	1.8	Ultisol
La Selva, Antioquia[2]	2200	18.0	1898	18.2	5.7	4.8	High organic, volcanic
Obonuco, Nariño[2]	2710	13.0	791	4.0	5.3	31.4	Volcanic
Seed Production:							
Dagua, Valle del Cauca	700	27.0	600	3.7	7.1	14.0	Loam-clay

1 All sites are in Colombia.
2 In cooperation with the Instituto Colombiano Agropecuario (ICA).

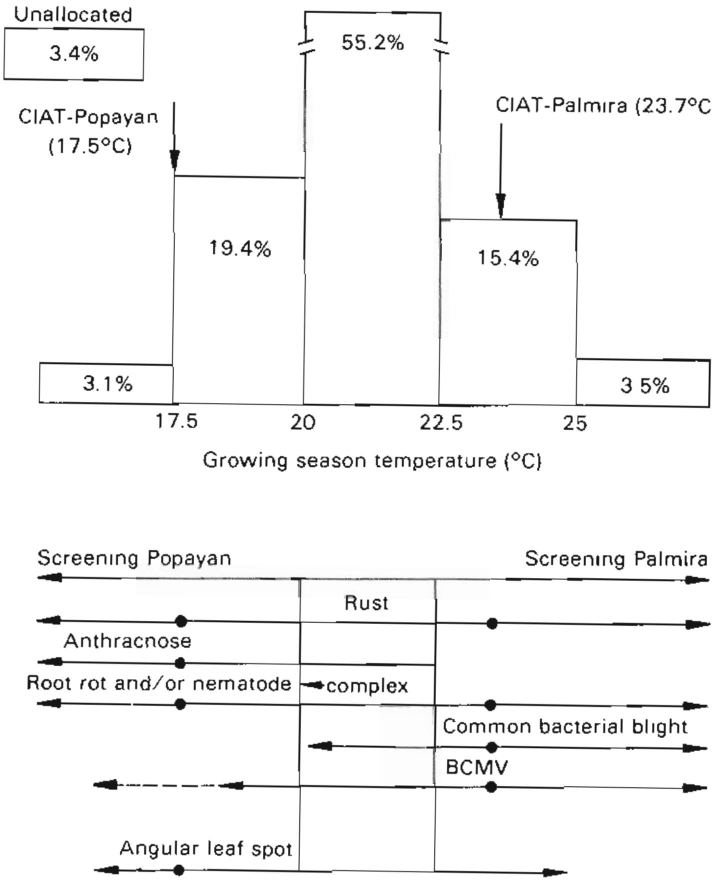

Fig. 2 *(Upper graph) Distribution of dry bean production with respect to temperature zones in Latin America. (Lower graph) Distribution of principal bean diseases over temperature zones in Latin America (based on estimates of their adaptational range).*

The major growth habit types which exist, and are primarily being sought during germplasm improvement, are described in Table 6.

While a modified backcrossing system is used for improving important cultivars grown in principal production zones, the pedigree breeding method or a modified pedigree system is extensively used to improve most other materials.

Table 6. Classifications of bean growth habits being selected for major cropping systems by the CIAT Bean Program.

Growth habit[1]	Major features
For Monoculture Systems	
Type I	Determinate growth habit: reproductive terminals on main stem and branches; no further main stem node and leaf production after flowering commences; main stem and branches generally strong and inflexible. These usually mature early and are suitable for shorter growing seasons.
Type IIa	Indeterminate growth habit: vegetative terminals on main stem and branches, limited node production on main stem continues after flowering; few erect and relatively inflexible branches borne on lower nodes; no or very weak guide development, lacks climbing ability.
For both Monoculture and Intercropping Systems	
Type IIb	Similar to IIa, but variable guide development with partial climbing ability. Support not necessary for production.
Type IIIa	Indeterminate growth habit: vegetative terminals on main stem and branches; node production continues on main stem and particularly on branches after flowering; flexible, well-developed and often prostrate branches borne on lower nodes; guide development limited and generally lacking climbing ability.
Type IIIb	As with Type IIa, but normally strong guide development on main stem; partial climbing ability; support desirable but not necessary for production.
For Intercropping Systems only	
Type IVa	Indeterminate growth habit: vegetative terminals on main stem and branches; heavy node development on main stem after flowering commences; few and flexible branches borne on lower nodes; pod load borne evenly along the length of the plant; vigorous climbing ability with support necessary for production.
Type IVb	Similar to IVa, but pod load borne mostly on upper nodes of main stem, very strong climbing tendency with support essential for production.

[1] Growth habit evaluation is made in the field during flowering, and a confirmation evaluation is made about 3-4 weeks after flowering terminates.

The growth habit classification has been expanded from the basic four types (I, II, III and IV) in order to describe the most important growth habit types under cultivation The classification does not necessarily cover the entire range of types found in *Phaseolus vulgaris*

Populations are handled in bulk before individual plant selections are made, e.g., for drought or low soil phosphorus. These are generally characters for which precise and dependable screening facilities are not presently available.

In all stages of germplasm development and evaluation, relatively low inputs and moderate stress to nutrients, water, diseases and insect pests are emphasized. Once a line has been selected within a project, usually in F_6 or F_7 generations,it is coded and advanced to the VEF for uniform and multiple character evaluation.

The Uniform Screening Nurseries

The Bean Program conducts two uniform evaluations each year, the First Uniform Nursery (VEF) and the Preliminary Yield Trial (EP). The term "uniform" refers to screening and evaluation, for any given character, under similar conditions and with equal emphasis on all entries irrespective of their source of origin, genetic constitution and stage of development. The VEF and EP form vital and essential links among different improvement projects and integrate activities of all team members and collaborators. Materials being tested in the International Bean Yield and Adaptation Nursery (IBYAN), the International Bean Rust Nursery (IBRN) and other international nurseries have to pass quality criteria set for these nurseries.

Both the VEF and EP are complementary nurseries and have the following common objectives: (a) to demonstrate the relative potentials and deficiencies of advanced selections from all sources; (b) to enable selection of candidates for the IBYAN, IBRN, and other international nurseries; and (c) to enable selection of parents for subsequent germplasm improvement.

The progression from VEF to EP and the characteristics evaluated in each take into account CIAT's research priorities as they relate to production problems, numbers of materials which can be handled, screening facilities, and the quantity of seed available.

First Uniform Nursery (VEF). It is open to all collaborators working in dry beans. Entries are selected from the germplasm bank, from materials provided by collaborators of national and international programs and from lines developed by CIAT. VEF entries must possess homozygous resistance to BCMV and be uniform for plant growth habit and grain type, in addition to the primary character(s) for which they were selected. Principal features of the VEF are listed in Table 7.

Table 7. Features of the First Uniform Screening Nursery (VEF) of the CIAT Bean Program.

A. Conducted from July to December.

B. Contains about 1000 experimental lines and cultivars selected from CIAT's breeding projects, the CIAT *Phaseolus* germplasm bank, and from national programs.

C. All entries are evaluated separately for resistance to: Bean common mosaic virus; Rust; Common bacterial blight; Leafhoppers; Antracnose; Angular leaf spot; besides, adaptation at CIAT-Palmira and Popayan.

D. Pathogen-free seed is increased for the next Preliminary Yield Trial (EP).

E. Entries selected for the next EP.

Preliminary Yield Trial (EP). The Preliminary Yield Trial (EP) is the second stage of the uniform testing of experimental lines of dry beans. All entries are selected from the previous VEF. This is the first yield evaluation of experimental lines and is planted at CIAT-Palmira and Popayan.

Besides yield, lines are tested for additional characteristics, many of which were not tested in VEF. Unlike the VEF, the EP is not restricted to Colombia but is evaluated at key sites around the world for specific adaptation and constraints not found within Colombia, e.g., BGMV, *Apion*, the bean fly and strains of anthracnose. Seed of each EP entry is kept for short-and long-term storage by the Genetic Resources Unit. An annual catalog of EP results is printed for use by collaborators. Small quantities of seed of complete or partial sets of an EP are available to interested scientists. Table 8 shows the essential features of the EP.

Table 8. Features of the Preliminary Yield Trial (EP) of the CIAT Bean Program.

A. Conducted from January to December.

B. Contains about 300 entries selected from the previous Uniform Screening Nursery (VEF).

C. Consists of replicated yield trials at two or more sites within Colombia, and in other locations as observation nurseries with interested collaborators, for specific problems.

D. All entries evaluated separately for: Web blight; Halo blight; Root rots; Ascochyta leaf spot; Gray leaf spot; Powdery mildew; White leaf spot; N fixation; tolerance to low soil P; drought; extreme temperatures; protein content and quality, cooking time; adaptation; photoperiod; and outside of Colombia for: Bean golden mosaic virus; Bean fly; and *Apion.*

E. Pathogen-free seed is increased for the International Bean Yield and Adaptation Nursery (IBYAN).

F. Entries are selected for the IBYAN and other nurseries.

Distribution of improved germplasm. Although the Bean Program distributes segregating populations and improved germplasm for specific objectives in the EP stage, emphasis is on distributing germplasm in the IBYAN.

International Bean Yield and Adaptation Nursery (IBYAN)

The International Bean Yield and Adaptation Nursery (IBYAN) is distributed internationally to key locations representing a wide range of major dry bean-producing areas. Objectives that were formalized in an international IBYAN workshop are to distribute and test, under a wide range of environments, outstanding commercial cultivars, germplasm bank accessions and experimental lines. Evaluation goals are: (a) to help identify high-yielding, stable materials for direct use as commercial cultivars; (b) to evaluate at each location a set of locally developed and adapted varieties representing a range of the best available materials in the region to be compared with international bean improvement progress; (c) to assess specific and general adaptation of beans; and, (d) to select parents for further improvement.

The IBYAN is composed of four categories of materials: germplasm bank selections, experimental lines developed by either national institutions or CIAT, and check entries. With the exception of the checks and entries selected from national programs, all other materials pass through the VEF and EP before entering the IBYAN. The check varieties include local varieties furnished by each collaborator, representing the best material available at each site; international checks—a group of varieties of known performance included in all trials over time; and elite checks—outstanding entries from previous IBYAN trials.

The IBYAN trials take into account seed color and size preferences (consumer's requirements) and agronomic requirements of the different cropping systems (farmer's requirements). This dual approach is basic in bean improvement. Bush bean materials are of specific seed color and size groups, eg., small seeded grouped into black, red, white nurseries, etc., medium or large white, red, canario, etc. Each group includes plant types that may be grown in monoculture, association, or relay cropping but do not need support for climbing. Climbing beans requiring support are distributed in three groups—small blacks, small reds and large-seeded of all colors. The essential features of the IBYAN are listed in Table 9.

The IBYAN is intended as the bridge between research station studies of promising, stable and widely adapted germplasm, and materials required for the on-farm trials and seed increase by national institutions. This, like the other trials, are free of charge.

Table 9. Features of the International Bean Yield and Adaptation Nursery (IBYAN) of the CIAT Bean Program.

A. Conducted from January to December.

B. Contains about 100 entries selected from the Preliminary Trial (EP) and from national programs; includes international, elite and local check cultivars.

C. Consists of separate, replicated trials for bush beans and climbers according to color and size of seed; each nursery contains no more than 20 entries.

D. Nurseries are tested worldwide.

E. Pathogen-free seed is increased to meet other requests.

Timely production of adequate quantities of pathogen-free seed is an integral part of the bean testing system (Fig. 1). Seed for IBYAN's is produced at Dagua, in a valley near Cali, where absence of commercial bean production and semi-arid conditions guarantee seed free of pathogens.

Other distribution channels

Additional germplasm exchange is accomplished by the international disease and insect resistance nurseries. These include nurseries for resistance to rust, BGMV, leafhoppers and *Apion*. Purposes of these nurseries are to distribute and evaluate sources of resistance to organisms or to races of pathogens not occurring in Colombia. International nurseries are also distributed for evaluating materials for nitrogen fixation and for tolerance to drought and extreme temperatures. Although no formal nursery is assembled, interested institutions can receive seed of segregating populations at any stage of development.

Agronomic Practices

Several components of agronomic research are best conducted by national programs. Most agronomic research such as fertilizer and herbicide response will be location-specific. Optimal plant density is specific to plant type, cropping system and location.

Improved varieties will not necessarily respond in the same way to inputs as traditional varieties. Since it will not be possible in the short term to incorporate resistance to all important local diseases, chemical control of some of these may be profitable in particular conditions. Hence, these types of applied research must also be done by national programs.

On the other hand, research in agronomic practices often as part of training which can be applied locally is done by the CIAT Bean Program. This includes methods and timing of fertilizer application, weed control and competition studies, and interactions of density on growth habit and nitrogen fixation.

CIAT also conducts agronomic research on associated cropping, mainly the association of beans with maize, cassava and coffee, to study relative planting dates and influences of associations on disease and pest incidence and on nitrogen fixation.

Farm-level trials. Specific technological packages should be evaluated in farm-level trials by both CIAT and national programs. A principal problem in producing new bean technology, both involving new varieties and new agronomic practices, is that farm-level conditions are often much more adverse than those of the experiment station. Moreover, at the farm, specific bean types are required to fit into a production system. Hence, there must be continual interaction between farmers and researchers, and this dialogue and feedback process is established through on-farm testing.

With on-farm testing, both the effects of new varieties and associated technology can be tested under farmers' conditions. This provides researchers with a direct source of information on technical and economic problems impeding the functioning or the adoption of their experimental results. This is especially important since the principal clientele, the small producers, have more difficulty in communicating directly with researchers.

Farm-level testing by the CIAT Bean Program is, therefore, not an extension activity but an integral component of the research process, and its focus is upon the feedback or measurement and evaluation of research performance and progress.

Farm-level testing is also utilized to develop and provide methodologies for other research institutions to verify their experimental results and farm-level constraints to the adoption of their new technology. The training component is an important aspect of this activity.

Training

Improving bean productivity cannot be done by an international center alone. A center needs to work within a collaborative network for germplasm improvement and distribution and development of agronomic practices. To be effective collaborators, national bean programs need scientists trained in applied, field-oriented bean research. Training programs provide the basis for forming the network. Training at the postgraduate level for research scientists is, therefore, an integral component of Bean Program activities. The program receives postgraduate trainees in three major categories.

1. Research trainees who participate in intensive short courses on all aspects of bean production research. One or two courses are given per year, in March and September. Applied field work is stressed as good research is based on good agronomy. The objective of these courses is to provide the theoretical basis as a preparation for postgraduate internship training. The development of audiotutorials and training materials has contributed significantly to training efficiency and quality.

2. Postgraduate interns who spend approximately one bean growing season at CIAT in their particular discipline. These scientists have first participated in the short course.

3. Students who undertake the thesis component of their higher degree studies at CIAT. Research is principally for M.S. theses; however, several Ph.D. dissertations have been based upon research at CIAT.

Table 10. Numbers of bean production and research workers receiving postgraduate training at CIAT, 1973-1980.

Training year	Training category				
	Postgraduate Research Interns	Research Scientists in short courses	Postgraduate Research Students[1]	Postdoctoral Fellows	Totals
1973	6	-	3	2	11
1974	11	-	3	3	17
1975	18	-	5	3	26
1976	26	-	6	4	36
1977	25	25	7	3	60
1978	26	50	7	3	86
1979	38	66	9	4	117
1980	22	47	5	4	78

[1] Candidates doing thesis work for the M.S. or Ph,D. degrees.

The number of people receiving training in the CIAT Bean Program has increased steadily since 1974 with most training positions usually occupied (Table 10). The Bean Program concentrates on training research scientists as its mandate is to develop and transfer improved technology to national programs. However, in-country training is becoming increasingly important to help train extension scientists. The Bean Program will assist national programs in such activities. To reach a wider audience and to support within-country training, more than 20 audiotutorial units have been or are being prepared. These are available to interested institutions who should request an up-to-date list of those available from CIAT's Communication Support Unit.

International Collaborative Activities

In 1975 the Bean Team assumed responsibility for developing a Latin American network of bean research workers. This network is now being expanded into Eastern Africa. Bean Program scientists felt each national program presented a unique situation, hence responsibility for coordinating activities with specific countries was divided between Program staff. While this concept has undergone some change with the naming of a regional network coordinator for Central America and an out-posted staff member in Peru, the scheme continues to function in most of South America.

The bi-monthly newsletter "Hojas de Frijol" is designed to improve communication and information within the Latin American research network. Additionally, to enhance transfer on information, an illustrated book, **Field Problems of Beans in Latin America**, and a monograph on disease, insect and other problems of bean production have been published.

To further intensify the network collaboration between national and international programs and among national programs, the Bean Team is planning to have additional regional out-posted staff over the next few years. Current plans are for one staff member in Eastern Africa (1982), one in Brazil (1983) and one in the Middle East (1985). These are in addition to the two now working in Central America and the Caribbean and in Peru. Their principal responsibility is to strengthen collaboration between research programs. Activities include selection of trainees, enhancing germplasm flow and generally assisting national programs in their activities.

The Team also collaborates with institutions outside of Latin America (Table 11). These institutions provide basic research and methodology development, for wich CIAT lacks facilities, adequately trained personnel or the comparative advantage to conduct such studies.

Table 11. Collaborative studies on beans conducted between CIAT and non-Latin American institutions.

Scientist	Institution	Areas of research
F.A. Bliss	Univ. of Wisconsin, U.S.A.	Protein quality
E. Drijfhout	Plant Breeding Institute (IVT), The Netherlands	Breeding for resistance to bean common mosaic virus, bean yellow mosaic virus and anthracnose
R. Marechal and	Univ. of Gembloux, Belgium	Interspecific crossing and species characterization
D. Mok	Oregon State Univ., U.S.A.	Interspecific crossing and cytogenetics

In 1974, in collaboration with the CIAT Library, a documentation and abstracting service was established to process and distribute citations and abstracts of bean literature to interested institutes and scientists. They are available on a monthly subscription basis and as annual compilations in book form (Fig. 3). More than 3000 articles have been processed and approximately 1000 abstracts continue to be processed and published annually in Spanish and English.

A series of workshops continues to be organized on bean production topics with participants invited from national programs and international institutions. In these, scientific information is exchanged and program strategies are discussed with national programs, providing a feedback to the Bean Program on its objectives and strategies.

Fig. 3. *Compilations of abstracts of current literature on bean research and production are distributed regularly in English and Spanish to workers around the world.*

Highlights of Research Achievements

Research results obtained by the Bean Program are available in CIAT Annual Reports and other publications. Some highlights of achievements are summarized here.

Germplasm Evaluation

Around 30,000 accessions of CIAT's *Phaseolus* spp. collection are stored in the Genetic Resources Unit (Table 12). These materials from some 20 countries represent a wide genetic diversity for most agronomic traits such as growth habit, flowering and maturity behavior, yield components, and disease and insect resistances. Additional collections are made to increase the available gene pool and to prevent loss of potentially valuable genetic variation. In 1979, for example, in collaboration with Instituto Nacional de Investigaciones Agricolas (INIA) in Mexico, the Genetic Resources Unit added over 400 new accessions to the ban Figures 4, 5, and 6 illustrate specific characteristics of some accessions. A catalogue was printed to document the first group of bank accessions. More than 11,000 samples have been shipped from the germplasm facility since 1974.

Superior selected accessions were initially assigned a "P" (promising) code, however, to avoid recoding already identified materials, P-codes are no longer used.

Table 12. Numbers of accessions acquired, increased in seed and evaluated in the CIAT *Phaseolus* germplasm bank (as of November 1978).

Species	No. of accessions	No. of accessions with seed increased	No. evaluated
P. vulgaris	26,333	12,200	9500
P. lunatus	1800	698	200
P. coccineus	1063	157	-
P. acutifolius	79	118	60
Other *Phaseolus* species including wild species	100	50	-
Totals	29,375	13,223	9760

Fig. 4. *Bean cultivars grown in Popayan show differences in maturity. Few really late-maturing cultivars have been identified.*

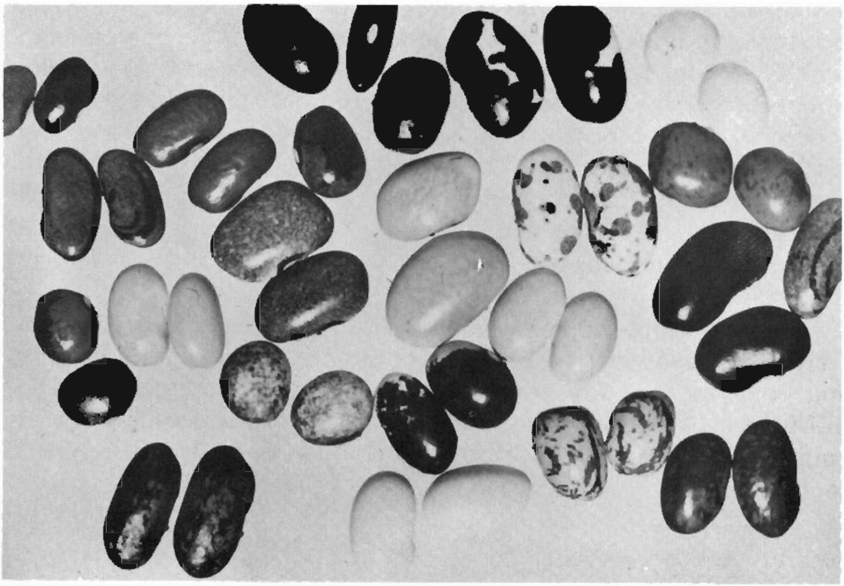

Fig. 5. **Phaseolus** *accessions in CIAT's germplasm bank differ markedly in size and color of seeds. Both factors are important in satisfying the needs of different national programs.*

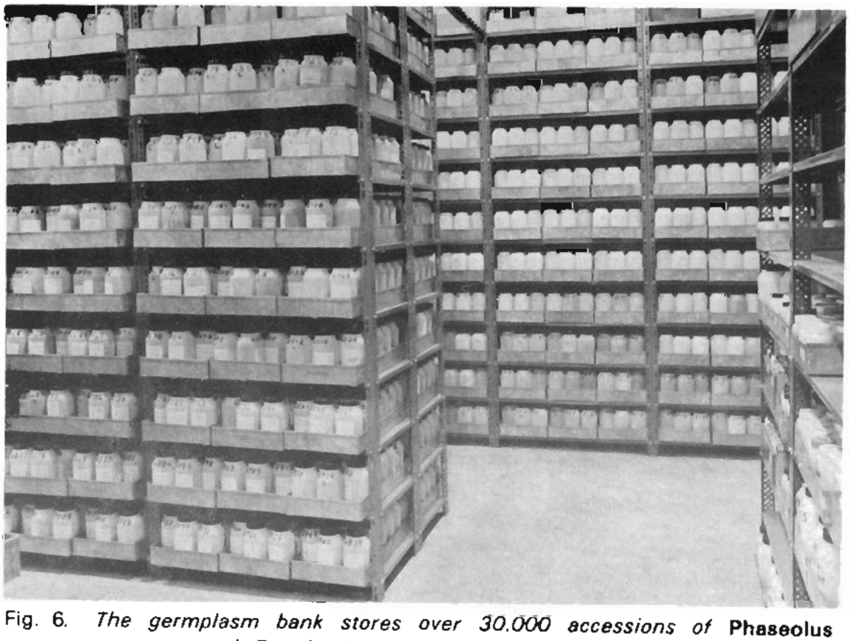

Fig. 6. *The germplasm bank stores over 30,000 accessions of* **Phaseolus** *species, mostly* **P. vulgaris.**

Instead, a computerized summary of superior national and international breeding lines and germplasm selections evaluated in each EP will be available annually, and seed of desired materials can be requested. All EP lines are resistant to BCMV and to at least one additional disease. Request for specific combinations of characters in germplasm shipments can be met quickly, as a result of computerizing all data.

Resistance to diseases

Accesssions are regularly evaluated for Program needs by the team members. Observation nurseries are often planted in CIAT-Palmira and Popayan, and are simultaneously screened for resistance to BCMV. All BCMV-resistant materials which are adapted in one or both sites enter the VEF for further testing as described in previous sections.

Table 13. CIAT **Phaseolus** germplasm bank accessions identified as sources of tolerance or resistance to major bean pathogens and pests in Latin America.

Pathogen or Pest	Source
Bean common mosaic virus	Many sources including Corbett Refugee, Topcrop, Widusa and a number of tropical, black-seeded cultivars.
Bean golden mosaic virus	Turrialba 1, Porrillo 1, Miranda 5 and ICA-Pijao.
Rust	Many sources including Mexico 235, Turrialba 1, ICA-Pijao, Mexico 309, Ecuador 299 and Redlands Greenleaf B.
Anthracnose	Many sources including Cornell 49-242, Kaboon, Mexique 222 or 227, and AB 136.
Leafhoppers	Many sources including PI 310 732, C63, S-630-R and Brazil 181 and 1097.
Common bacterial blight	PI 207 262, G.N. Nebraska #1 Sel 27 and Jules.
Angular leaf spot	Caraota 260, Epicure and 10233 MM.
Halo blight	Redkote and Great Northern UI 16831.
Powdery mildew	Topcrop and PI 306 149.
Root rots	PI 203 958, PI 165 435, Porrillo Sintético, ICA-Tui, Cubagua and Black Turtle Soup.

Table 14. Tropically adapted *Phaseolus* germplasm accessions with multiple resistance to diseases and insect pests most common in Latin America.

Germplasm Identification	Origin	Seed color	Growth habit	Widely dispersed diseases and pests						Locally important diseases		
				Leaf-hopper[1]	Bean common mosaic virus[1]	Rust[1]	Anthrac-nose[1]	Common bacterial blight[2]	Angular leaf spot[2]	Web blight[1]	Gray leaf spot[2]	Ascochyta leaf spot[2]
Carioca	Brazil	Creme-brown	III	R	R	S	I	4	3	S	1	4
G 1753	Costa Rica	Black	II	I	R	S	S	4	1	R	1	3
G 2618	Mexico	Creme	III	S	R/S	Ip	R	4	3	-	1	3
G 5158	Brazil	Creme	I	I	R	S	S	4	3	S	1	4
G 5699	Honduras	Creme	II	I	R	S	S	4	1	S	2	3
G 3834	Costa Rica	Black	II	S	R	R	S	4	1	S	5	4
G 3843	U.S.A.	Tan	I	S	R	S	S	4	4	S	1	5
G 4017	Brazil	Creme	III	R	R	S	I	4	3	S	1	4
G 5122	Brazil	Tan	II	S	R	S	I	4	4	S	1	4
G 5743	Brazil	Black	II	I	R	S	I	4	2	S	3	4
G 6413	Cuba	Black	III	I	R	S	S	3	1	S	1	3

[1] Ratings: R=resistant; I=intermediate; *Ip*=intermediate with small pustules; S=susceptible.

[2] Ratings: 1=immune; 2=resistant; 3=tolerant; 4=susceptible; 5=very susceptible.

Table 15. Reactions to bean rust *(Uromyces phaseoli)* of the most widely resistant entries in the International Bean Rust Nursery, during 1975-1978. (Data are numbers of locations where the entry received the rating indicated.)[1]

Identification	No. of locations														
	1975					1976					1977-78				
	Im	R	Int	S	No data	Im	R	Int	S	No data	Im	R	Int	S	No data
Compuesto Chimalteco 3	4	3	2	1	5	5	9	2	1	0	2	9	4	1	1
Turrialba 1	4	3	2	3	3	3	7	6	1	0	3	6	4	3	1
ICA-Pijao	3	1	4	3	4	3	6	7	1	0	3	6	4	4	0
Mexico 309	6	5	1	0	3	6	3	3	2	0	3	7	1	1	0
Mexico 235	2	1	2	0	10	6	4	4	2	1	5	6	2	2	2
Cuilapa 72	4	7	1	0	3	8	3	3	3	0	7	7	3	0	0
Ecuador 299	5	7	1	0	2	3	6	6	2	0	4	6	4	2	1
Cornell 49-242	3	5	4	1	2	2	4	9	2	0	1	6	7	3	0
Redlands Greenleaf B	7	3	2	0	3	2	8	5	2	0	3	11	2	0	1

[1] Ratings: Im=immune; R=resistant; Int=intermediate; S=susceptible

In addition to BCMV, valuable sources of resistance to rust, angular leaf spot, anthracnose, common bacterial blight, bean golden mosaic virus and web blight (Table 13) or combinations of these (Table 14) have been identified. Although of lower priority, sources of resistance or tolerance to other diseases, such as root rots, halo blight, and various foliar pathogens were also identified.

Initial evaluations at CIAT-Palmira showed different rust resistance mechanisms —slow rusting, necrotic reaction and limited pustules— and their stability is now being measured. A second level of germplasm screening for rust resistance in the International Bean Rust Nursery (IBRN) has revealed cultivars with resistance to races of the pathogen in several areas, but none with resistance to rust at all locations tested (Table 15) (CIAT, 1979b). These and additional materials are being evaluated in subsequent IBRN's and used as parents.

Similarly, the Bean Golden Mosaic Nursery demonstrated resistance sources to this important virus disease. As a consequence, multiple-disease resistant lines including resistance to BGMV were developed and released in Guatemala as new varieties.

Resistance to insects

Fig. 7. *A resistant and a susceptible variety to the leafhopper* (**Empoasca kraemeri**) *under dry season conditions at CIAT-Palmira.*

Among insect pests, emphasis has been placed on the leafhopper *(Empoasca kraemeri).* All available bank accessions have been evaluated for tolerance, and differences in the susceptibility of cultivars are evident (Fig. 7). Levels of resistance encountered this far are adequate to provide protection during average leafhopper attacks but need to be increased for protection during heavy attacks. Materials of some preferred grain types still lack adequate levels of resistance. Studies have also confirmed and/or identified sources of resistance to *Apion,* and spider mites.

Other useful variability

Besides disease and insect resistance sources, other valuable genetic variability has been encountered in the germplasm bank. High-yielding varieties such as ICA-Pijao, Porrillo Sintetico, Jamapa and non-black accessions such as Bico de Ouro and NEP-2 are used as parents in the breeding program. Identified accessions with erect plant type and variability in pod and leaf size may be of value in raising yield potential. Other characteristics used in parental selection include the ability to fix atmospheric nitrogen in symbiosis with *Rhizobium,* tolerance to drought stress, and to low soil phosphorus and extreme temperatures, as well as insensitivity to photoperiod (Table 16). It appears that tolerance to low soil phosphorus has to be measured by yield reduction in stressed versus non-stressed plots (Table 17) , as good vegetative growth may occur but pods do not fill. Leading brazilian commercial cultivars were among the most tolerant ones to low soil phosphorus. The Program selects entries efficient in phosphorus utilization and responsive to phosphorus inputs (Fig. 8). Figure 8 also reflects the Bean Team's general philosophy of seeking genetic variability which permits as high a yield as possible under low-input management but also provides a yield response to higher levels of management.

Table 16 Some desirable agronomic characteristics of selected lines and cultivars that show these factors.

Characteristic	Identification	Growth habit	Seed color	Seed size	Origin
Tolerance to low soil P	Carioca	III	Creme-brown	Small	Brazil
	G 4000	II	Brown	Small	Costa Rica
	G 5201	I	Black	Small	Mexico
	Iguacu	II	Black	Small	Brazil
Tolerance to water stress	BAT 332	II	Creme	Small	CIAT
	BAT 440	II	Black	Small	CIAT
	G 1224	II	Yellow	Small	Mexico
	G 3689	II	Black	Small	El Salvador
	G 3719	II	Tan	Small	Mexico
Active fixation of N_2	BAT 76	II	Black	Small	CIAT
	BAT 154	III	Black	Small	CIAT
Tolerance to low temperature	G 22	II	Creme-mottled	Medium	Canada
	Diacol Andino	I	Red-mottled	Large	Colombia
	G 404	III	Creme-mottled	Medium	South Africa
Tolerance to high temperature	G 3689	I	Black	Small	EL Salvador
	G 4525	II	Black	Small	Mexico
	G 1864	III	Black	Small	Honduras
Early maturity	A 32	II	Brown	Small	CIAT
	Carmine	I	Brown	Large	U.S.A
	G 122	I	Creme-mottled	Medium	India
	G 153	III	Red-mottled	Medium	Turkey
Late maturity	77ICA10310	II	Creme	Small	Colombia
Short internodes	A 30	II	Yellow	Small	CIAT
	77ICA10218	II	Creme	Small	Colombia
Small foliage	G 2402	II	Creme-mottled	Medium	Mexico
	G 6003	III	White	Small	Mexico
Lanceolate leaf	LL 1	II	Brown	Small	CIAT
Outrigger raceme	G 9981	I/III	Variable	Small	Mexico
	G 9986	I	Variable	Small	Mexico
Small pod	G 1531	III	White	Small	Chile
	G 7460	II	White	Small	Australia
	77ICA10423	II	Creme	Small	Colombia

Table 17. Dry bean materials tolerant to adverse soil conditions in two semesters of field screenings at CIAT-Quilichao.

Identificacion	Seed color	Yield (kg/ha) Stressed plot	Yield (kg/ha) Optimum plot
Tolerance to low soil P (1978A)			
Pecho Amarillo	Black	1590	2110
Actopan	Black	1490	1940
PI 310 739	Black	1390	1930
PI 310 797	Black	1310	1760
Olive Brown	Creme	1290	2460
Tolerance to low soil P (1978B)			
FF1238-CB	Black	1297	1685
BAT 85	Creme	1117	1482
BAT 58	Black	1032	1782
BAT 83	White	1032	1457
BAT 110	Black	1027	1612
Tolerance to high soil Al			
BAT 97	Gray	1280	1920
BAT 96	Gray	1210	1940
Brazil 349	Creme	1160	2620
BAT 47	Red	1160	2250
BAT 58	Black	1150	2440

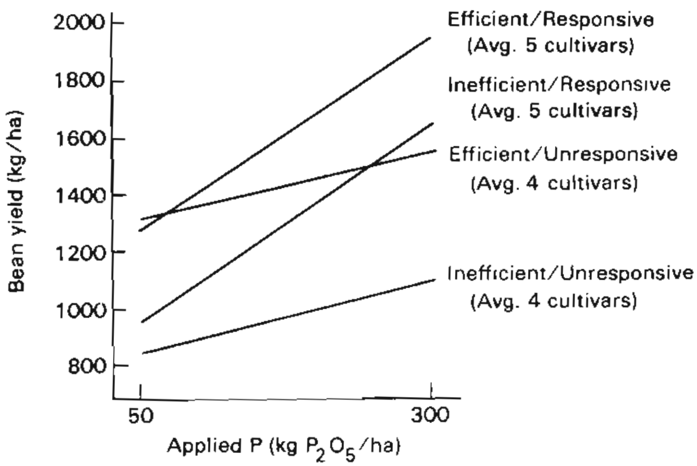

Fig. 8. *Yield efficiency of* **Phaseolus vulgaris** *cultivars at a low level of soil phosphorus and their responsiveness to additional phosphorus.*

Development of Genetically Improved Germplasm

Varietal improvement has evolved considerably since the modest effort initiated in 1974. Currently about 500 parents are utilized in the crossing program and more than 1500 different crosses are made annually (Fig. 9). These provide more than 200,000 F_2 plants to be evaluated under field conditions each year. Lines leaving the varietal improvement programs are coded and enter the VEF for adaptation and multiple disease and insect resistance testing and subsequent selection and testing in the EP. Table 18 shows some of the more promising breeding lines combining multiple resistances in several seed colors that were identified during the 1979 evaluations.

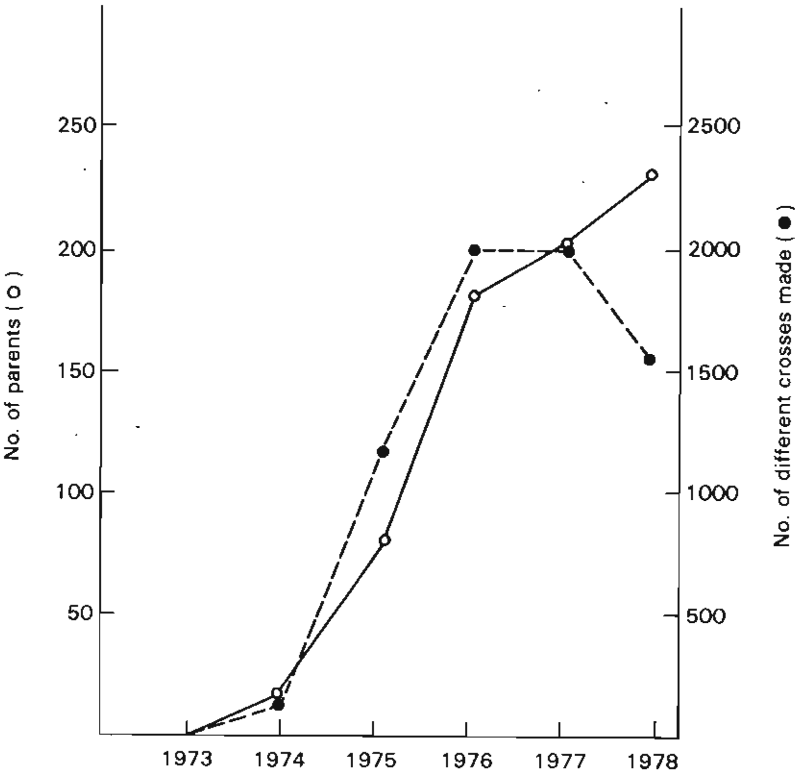

Fig. 9. *Development of the CIAT dry bean crossing program during 1973-78. The number of hybridizations is now relatively stable although numbers of parents utilized continue to increase.*

Table 18. Tropically adapted dry bean breeding lines with multiple resistance to diseases and insect ,pests most common in Latin America.

Breeding line identification	Origin	Seed color	Growth habit	Widely dispersed diseases and pests						Locally important diseases		
				Leaf-hopper[1]	Bean common mosaic virus[1]	Rust[1]	Anthrac-nose[1]	Common bacterial blight[2]	Angular leaf spot[2]	Web blight[2]	Gray leaf spot[2]	Ascochyta leaf spot[2]
BAT 44	CIAT	Brown	III	R	R	S	R	4	5	-	1	2
BAT 76	CIAT	Black	II	I	R	R/Ip	I	4	4	I	2	4
BAT 93	CIAT	Yellow	II	S	R	R	R	2	4	S	2	4
BAT 260	CIAT	Black	II	I	R	R	I	4	5	S	5	4
BAT 317	CIAT	Tan	II	S	R	R	R	4	5	S	1	4
BAT 332	CIAT	Creme	II	S	R	R	I	4	3	S	2	4
BAT 338	CIAT	White	III	I	R	R	S	3	3	I	2	4
BAT 448	CIAT	Black	II	S	R	Ip/R	R	4	5	I	5	4
EMP 21	CIAT	Black	II	R	R	S	I	4	5	S	3	4

[1] Ratings R=resistant; I=intermediate; Ip=intermediate with small pustules; S=susceptible.

[2] Ratings 1=immune; 2=resistant; 3=tolerant; 4=susceptible; 5=very susceptible.

All lines leaving the Program are now resistant to BCMV. The Bean Team has incorporated the dominant I gene along with desirable strain-specific genes in some advanced lines. This is done in collaboration with the Plant Breeding Institute of the Netherlands. Progenies are tested in CIAT for adaptation to Latin American conditions.

Since 1974 an active program of preliminary, uniform and international yield trials has been conducted in multiple locations. Initially these trials included only germplasm accessions but now they consist predominantly of advanced breeding lines. In initial selections from the germplasm bank, the high-yielding cultivars were principally black-seeded. Now, however, advanced breeding lines with other seedcoat colors equal or have surpassed the yield potential of black-seeded selections.

While the 20 highest yielding materials in the 1979 EP yielded an average of 3.58 ton/ha (ranging from 3.42 to 4.0 ton/ha) under intensive management, more importance is given to lines' performances under more rustic management conditions approaching farmers' traditional practices. Yield data of the 1978 and 1979 EP trials conducted under this management level are given in Tables 19 and 20. In the 1978 yield trials, the best CIAT line outyielded the best local variety by up to 43 percent and the best breeding lines outyielded the best parents by 57 percent.

Table 19. Yields of advanced lines in 1978 Preliminary Yield Trial (78EP), at CIAT-Palmira.

Seed color group	Rankings of lines	Yield (t/ha)		
		CIAT breeding lines	Parental group	Germplasm accessions
Red	Best line	2.94	1.87	2.24
	Mean of 10 best lines	2.05	1.48	1.44
	Mean of all lines	1.72	1.19	0.97
Black	Best line	2.62	2.24	2.05
	Mean of 10 best lines	2.33	2.02	1.82
	Mean of all lines	1.84	1.51	1.41
Other colors	Best line	2.55	2.00	1.78
	Mean of 10 best lines	2.20	1.73	1.48
	Mean of all lines	1.79	1.23	1.09

Table 20. Yields of best breeding lines and best check varieties in 1979 Preliminary Yield Trial (79EP), at two locations.

Seed color group	Lines	Yield (t/ha)	
		CIAT-Palmira	Popayan
Red	Breeding lines	2.43	2.48
	Check lines	2.22	1.98
Black	Breeding lines	3.01	3.29
	Check lines	2.63	2.63
Other colors	Breeding lines	2.69	2.97
	Check lines	2.41	2.51

Although the principal product of the Bean Program is finished breeding lines, national programs request specific crosses and select from among the best advanced lines identified each year. Network breeders have promoted CIAT crosses into promising advanced lines.

One example is the Acacia lines selected out of early segregating materials by Honduran breeders. Three of these promising lines showed average yields of 2.32 ton/ha, compared to 1.69 ton/ha for five local varieties, a difference of 0.63 ton/ha. These lines combine resistance to BCMVand rust with increased yield potential and plant type, and one,Acacia 4,was recently released as a new variety. Some BGMV-resistant: selections made in Central America and Brazil have substantially outyielded their parents when subjected to the virus, while maintaining their yield potential in the absence of the virus (Table 21). Three new BGMV varieties were recently released in Guatemala. Seed multiplication of such newly released varieties have been initiated.

The best EP selections together with national program entries enter the IBYAN. Numbers and locations of IBYAN shipments over three years are given in Table 22 and include both bush and climbing trials. While the first IBYAN of 1976 contained only germplasm bank accessions, current trials are principally composed of improved lines. Results of the first IBYAN (1976) from 50 locations ranging in latitude from 1°S (Boliche, Ecuador) to 55°N (Cambridge, England) for both tropical and temperate locations, showed the mean yield of the best five IBYAN entries was 31 percent better than that of the best local cultivars (Table 23).

Table 21. Performance of materials bred and selected for resistance to bean golden mosaic virus, at Instituto de Ciencia y Tecnología Agrícolas (ICTA), Guatemala, 1978.

Breeding line or parents	Bean golden mosaic virus rating[1]	Yield (kg/ha)	
		with virus present	without virus
D83 (FF2152-1)	5.0	1483	2106
D30 (FF1006-4)	5.0	1300	2478
D82 (FF2152-CM(3))	6.0	1288	-
D35 (FF1012-CB-CB-CM(12))	5.0	1233	2420
D52 (FF2175-M-4)	6.0	1184	-
ICA-Pijao (Suchitan)	5.7	1111	2462
Porrillo Sintético	6.3	897	-
Turrialba 1	5.7	651	2196
ICA-Tui	5.3	479	-
Pecho Amarillo (Local variety)	8.0	546	2540

[1] Rating scale: 1=no symptoms; 9=severest symptoms.

Table 22. Regional distribution of International Bean Yield and Adaptation Nursery (IBYAN) trials, 1976-1978.

Region	Nursery sets distributed		
	1976	1977	1978
Latin America	69	80	136
North America, Europe and Australia	8	9	5
Asia	9	14	0
Africa	4	15	9
Totals	90	118	150

Yield stability of the 20 IBYAN entries varied across locations. Five black-seeded type II cultivars (PI 309 804, Jamapa, ICA-Pijao, 51051, and Porrillo Sintetico) not only showed high average yields, but also relatively stable performance between sites (Fig. 10). Type I (determinate) cultivars gave disappointing yield and yield stability.

Table 23. Yields of selected best entries and local checks in 1976 International Bean Yield and Adaptation Nursery (IBYAN) in tropical and temperate zones.

Zone	Type of entry		Yield (kg/ha)	
			Avg. of best 5 entries	Avg. of best entry
Tropical	Germplasm selections		1613	1828
	Local checks		1170	1506
		Difference	443	322
Temperate	Germplasm selections		2450	2730
	Local checks		1950	2416
		Difference	500	314

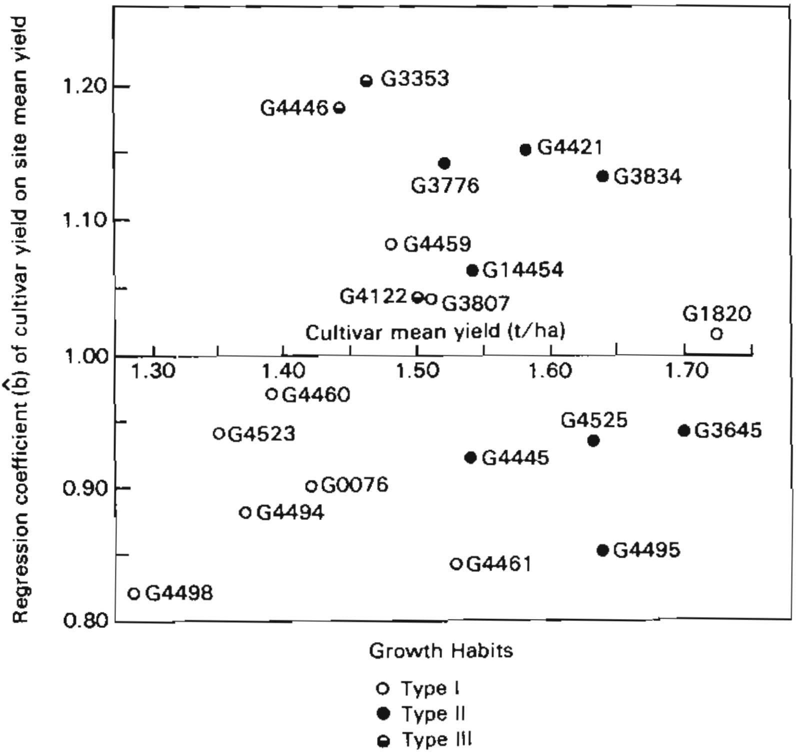

Fig. 10. *Yield potential and adaptation for the 20 dry bean cultivars in the 1976 International Bean Yield and Adaptation Nursery (IBYAN) as measured by cultivar mean yield and the regression coefficient of cultivar yield on site mean yield.*

Unfortunately, these Type I varieties are often large-seeded commercial types whose market value is substantially higher than smaller-seeded varieties in many countries. Currently both bush and climbing bean IBYAN's are divided in small sets of lines of one commercial color group. Thus any collaborator only will receive lines of commercial seed type in an IBYAN.

Agronomic Practices

Most bean producers cannot make large expenditures for inputs, hence considerable emphasis is given to development of technology utilizing low fertilizer inputs.

Phosphorus

Many Latin American soils are deficient in phosphorus and fertilization is necessary to get good yields. Critical levels of phosphorus for bean growth at Popayan have been determined to be about 15 ppm (Bray II). To keep applications as low as possible, varietal differences in tolerance to low phosphorus are sought. Large genetic differences have been found in the ability to produce yields under low soil phosphorus levels. The Bean Program has directed part of its resources to incorporating and augmenting this characteristic in germplasm intended especially for Brazil. When fertilizers are applied, results have shown that band applications in phosphorus-fixing soils was advantageous when triple super-phosphate was used. However, some rock phosphates, when broadcast, are more residual and economical.

Fixation of nitrogen

Atmospheric nitrogen fixation at seasonal rates in excess of 40 kg of N_2 fixed/ha has been achieved, both under conditions at Popayan and CIAT-Quilichao (CIAT, 1979). Such fixation rates are at least equal to those reported for other grain legumes. Fixation by determinate, early-flowering cultivars has proved weak, as shown in Figure 11. In several experiments nitrogen fixation (as measured in C_2H_2 reduction) has been positively correlated with carbohydrate supply to nodules, again with major differences apparent between cultivars (Fig. 12).

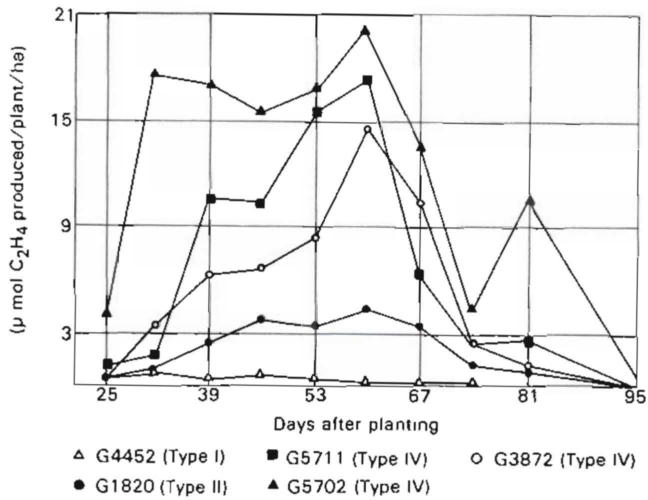

Fig. 11 *Growing season profiles of nitrogen (C_2H_2) fixation in five* **Phaseolus vulgaris** *cultivars differing in growth habits.*

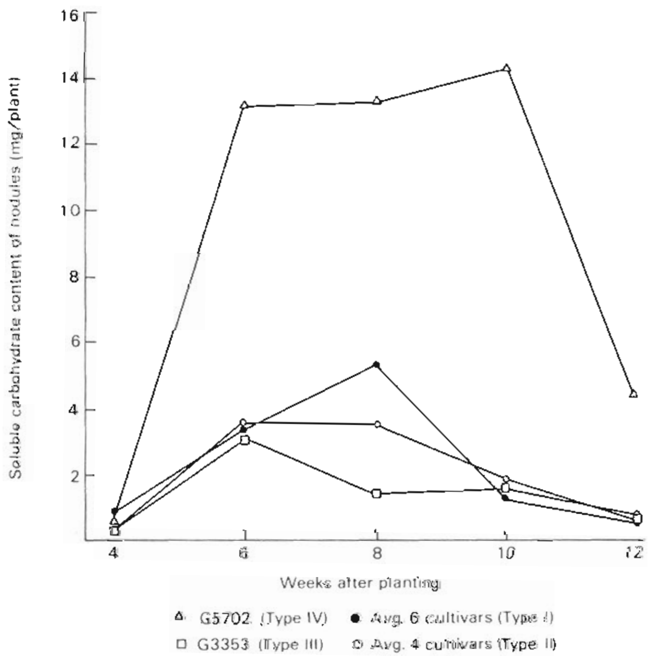

Fig. 12. *Differences in soluble carbohydrate content of nodules in* **Phaseolus vulgaris** *cultivars at different growing cycle stages.*

When the effect of cultural practices was studied, association with maize reduced nitrogen fixation in bush beans, but had little effect on the fixation rate of climbers. Optimum planting density for nitrogen fixation was near the optimal for maximum yields, however phosphate fertilization greatly increased nitrogen fixation.

CIAT maintains a documented collection of some 300 cultures of *Rhizobium phaseoli,* which are available either as cultures or peat inoculants to other scientists. Currently, the best strains are tested in an International Bean Inoculation Trial (IBIT) in many countries.

Pest control

Diseases. The production of pathogen-free foundation seed (clean seed) is an important research area of the Program. Studies of seed saved by farmers in Colombia's Huila region showed low germination rates and many fungal contaminants. CIAT has stressed the "cleaning" of such seed to minimize the possibility of distributing pathogens in seed shipments and for increasing germination and early stand (Fig. 13).

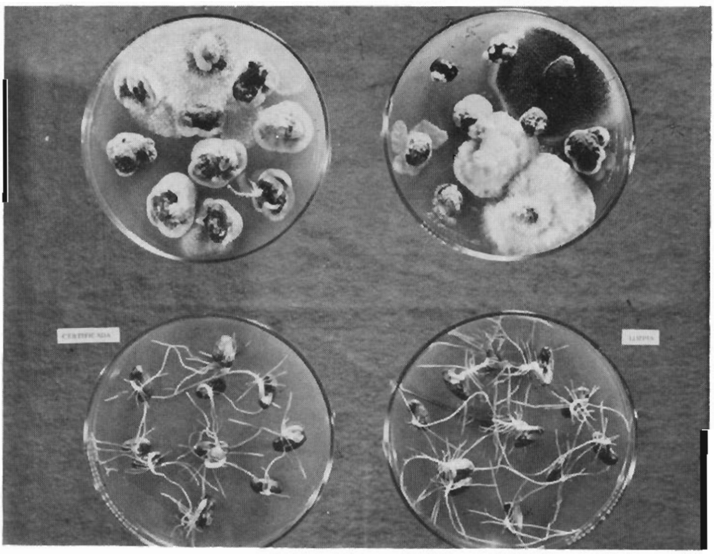

Fig. 13. *Incidence of internal seed-borne fungi in farmers' seed from Huila, Colombia (upper), compared to seed grown at CIAT under protected conditions (bottom). All seeds were surface-sterilized before placing on H_2O- Agar medium*

Various types of improved seed, including certified, protected and pathogen-free seed from Chile and from Dagua (CIAT's seed production site), did not have yield advantages over farmers' seed, when tested in on-farm trials. The principal reason appears to be the difficulty of completely roguing BCMV in highly susceptible varieties. Since BCMV can substantially reduce yields and clean seed appears to be an inadequate substitute for resistance, the Bean Program only releases lines for testing that have resistance to BCMV. In such lines, seed free of other pathogens is expected to have a larger yield advantage and is tested again on farms. Additionally, farmers seem to select the best seed for future plantings. When new varieties are produced, the importance of improved seed production techniques is expected to substantially increase. The Seed Unit at CIAT is collaborating with several national programs to establish seed production schemes.

Insects. Several studies have been conducted to determine critical insect pest levels. Chrysomelid attack at the seedling stage can substantially reduce yields; however, in later stages its influence on yields is minimal.

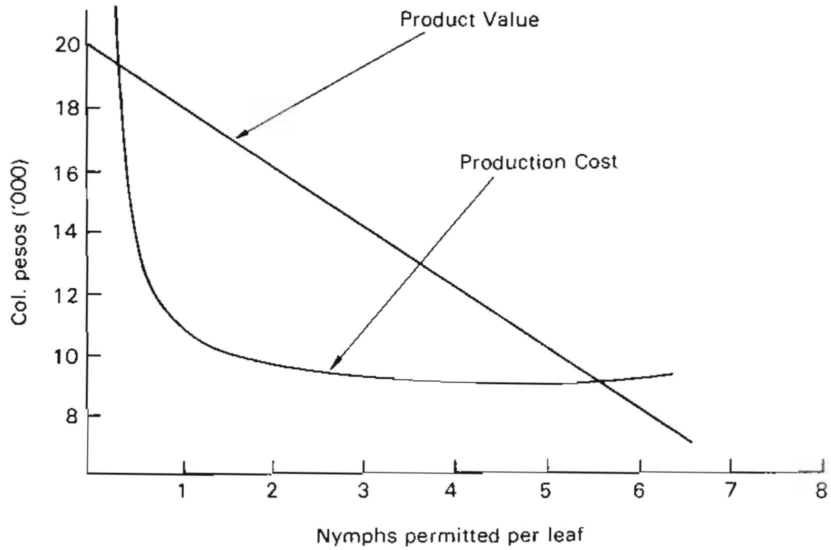

Fig. 14. *Product value and production costs for beans when nymphal populations of* **Empoasca kraemeri** *were controlled at different levels of infestation*

Studies relating leafhopper populations and damage with production costs indicate an optimum return for the farmer by controlling *Empoasca* populations when they reach about 1 nymph/leaf (Fig. 14). *Empoasca* control is most important during the flowering period. Mulching has been shown to reduce *Empoasca* attack in addition to reducing weed growth and preserving soil moisture.

Treating harvested seed with small quantities of vegetable oils, a technique used earlier for cowpeas in Africa, has been highly successful in controlling the storage pests *Zabrotes* and *Acanthoscelides*. Only 5 ml of oil/kg eliminated insect populations but did not affect germination or cooking quality (Table 24).

Table 24. Reproduction of *Zabrotes subfasciatus* on shelled dry beans treated with vegetable oils.[1]

Type of oil	Treatment (ml oil/ kg seed)	Adult mortality (%)		No. eggs/ replication	No. of adults/ replication
		2 days	9 days		
Soybean	1	0	62	182	24
	5	100	100	<1	<1
	10	100	100	0	0
Mixed	1	6	86	136	33
	5	99	100	8	0
	10	100	100	0	0
Maize	1	1	93	125	22
	5	100	100	10	0
	10	100	100	0	0
Control	0	0	49	227	142

[1] Values for each treatment are the average of five replicates with 100 g seed each, infested with seven pairs of adults.

Bean/maize association

Studies of the association of beans and maize have advanced considerably since their initiation in 1975. Associated cropping of beans and maize has reduced attacks of certain diseases and insect pests, while increasing others. Both leafhoppers and common bacterial blight incidences appeared lower under this cropping system.

Experiments have shown reduced yields of maize varieties even at lower bean densities. Although optimum densities for each species must be defined, density alone is not an important variable determining yields. Density response will depend upon the varieties of beans and maize, location, input use and other factors of weather and disease/pest incidence (Francis *et al.,* 1978).

In one series of trials, association with maize reduced bush and climbing bean yields 58 and 64 percent, respectively. Maize yields were reduced an average of 30 percent by association with beans. The highest association yield achieved in experimental plots was 2.2 tons of beans and 5.5 tons of maize per hectare.

Yields above 4.5 t/ha have been achieved in CIAT-Palmira and Popayan for climbing beans supported on mature maize stems and more than 5.0 t/ha on bamboo/wire trellises. Numerous experiments to evaluate the genotype x system interactions for beans have indicated climbing bean lines should be selected under the cropping system for which they are intended. Specific and different types of beans and maize appear necessary, depending on whether direct association or relay cropping systems are utilized. For planting in direct association, a vigorous climbing bean (Type IVb) should be sown with a maize variety intermediate in height (2.5m) and having narrow leaves and lodging resistance. A moderate climber (Type IVa) planted with a tall (2.5 m), lodge-resistant maize is better suited for relay systems.

Growth of the Bean Plant

Whereas the genus *Phaseolus* has been studied intensively in temperate regions, physiological studies under tropical or semi-tropical conditions have been limited. Growth analysis experiments (Table 25) helped identify yield-limiting factors in five varieties, from the four growth habit groups defined by CIAT. The earliness of Type I plants limits the maximum leaf area and leaf area duration. Increased node development and leaf area were strongly related to yield in all varieties.

Table 25. Yield parameters for *P. vulgaris* cultivars of differing growth habits in growth analysis experiment, at CIAT-Palmira.

Parameter	Cultivar and (growth habit)				
	G 4452 (I)	G 1540 (I)	G 4495 (II)	G 3353 (III)	G 2525 (IV)
Mean yield, 14% moist. (g/m^2)	230	242	273	322	365
No. of experiments	3	2	9	3	3
Pod number/m^2	142	246	216	265	294
Beans/pod	2.55	3.20	5.56	4.36	5.69
Bean size (mg/bean)	544	272	195	240	185
Maximum node number/m^2	363	413	587	923	864
Maximum leaf area index (LAI)	3.03	3.43	3.57	4.14	5.99
Leaf area duration[1] (E-F)[2]	23	18	36	41	81
Leaf area duration (F-M)	95	96	94	123	180
Leaf area duration (E-M)	118	114	130	164	261
Days to flowering (E-F)	25	25	33	33	41
Days to maturity (E-M)	64	67	73	81	89
Yield/day (planting to maturity)	3.31	3.36	3.51	3.73	3.88
Yield/leaf area duration[3] (E-M)	1.95	2.12	2.10	1.96	1.40

1 Leaf area duration (LAD) = m^2 days/m^2

2 E=emergence; F=flowering; M=physiological maturity

3 Leaf area efficiency=g/m^2 days/m^2 land area.

Table 26. Flowering and pod abscission for three *P. vulgaris* cultivars, at CIAT-Palmira, 1975.

Parameter	Cultivar and (growth habit)		
	G 4452 (I)	G 4495 (II)	G 2006 (III)
Total number flowers/plant	37	39	39
Pods abscissed, < 3 cm	21	20	13
Pods abscissed, >3 cm	7	5	9
Pod-set efficiency (%)	24	36	44
Flowering period (days)	14	17	29
Time to form 60% of flowers (days)	4	10	10
Pod-set efficiency during first 60% flowers formed (%)	36	60	70
Pod-set efficiency during last 50% flowers formed (%)	7	0	6

Flower and pod abscission has proved a major problem in beans with all cultivars tested showing almost 70 percent flower and pod abscission (Table 26). Abscission is greatest in flowers and pods high in the canopy, on branches, or in the higher positions within a raceme. First-formed flowers are more likely to mature than those produced later.

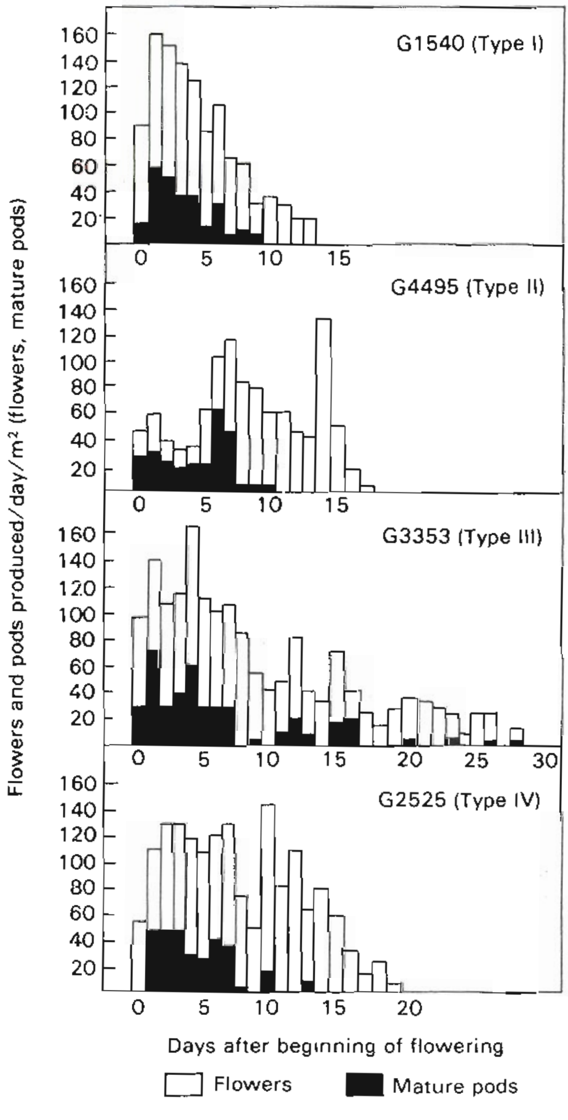

Fig. 15. *Number of flowers and pods produced by* **Phaseolus vulgaris** *cultivars of the four growth habit groups.*

Growth habit groups have distinctly different patterns of flower production. This is an important finding for beans produced under rainfed conditions (Fig. 15).

Farm Testing of New Technology

The final test of experiment station technology occurs on farmers' fields and in the marketplace. Farm testing was done in major bean zones in Colombia. Simple agronomic packages including chemicals, optimum plant support and better weed control substantially increased yields and farm income without large increases in input costs (Table 27).

Farm trials have shown potential gains of 1 t/ha of beans with improved agronomy. Approximately half of these grains can be obtained with low but specific input use, while the other half depends on higher input use (Fig. 16). Currently the first new improved lines from uniform yields testing are being tested at the farm level.

Table 27 Increases in costs and incomes from using simple agronomic practices in bean production on small farms in three regions of Colombia, 1978.

Region	Practice	Yield increase (%)	Cost increase (Col. pesos/ha)	Cost increase (%)	Net income gain (Col. pesos/ha)	Net income gain (%)	Comments
Huila	Curative spraying against leafhoppers and anthracnose, two weedings	50	3791	37	7745	72	Three-quarters of farms did not have fertility problems and there was no response to fertilizer. When there was a critical fertility problem, it had to be corrected first.
Antioquia	Substitution of Benlate for Manzate in fungicide treatments	55	2661	14	22,314	86	A mix of chemicals has to be utilized to avoid a long-run selection process of resistance in the anthracnose fungus.
	Increased planting density reinforced with stakes	37	5560	26	20,588	43	Stakes are expensive but available in the region. Increased density results in a statistically significant disease increase, hence, this practice is based upon the use of the appropriate chemicals first
Restrepo	Increased density; use of Benlate; application of micronutrients, weeding	34	5633	35	4588	33	Beans are not a major crop in this marginal coffee area. Soil fertility is a problem with mean soil P 2-3 ppm. Hence, response to fertilization is good, and the returns to the low-cost agronomy package are less than in Huila.

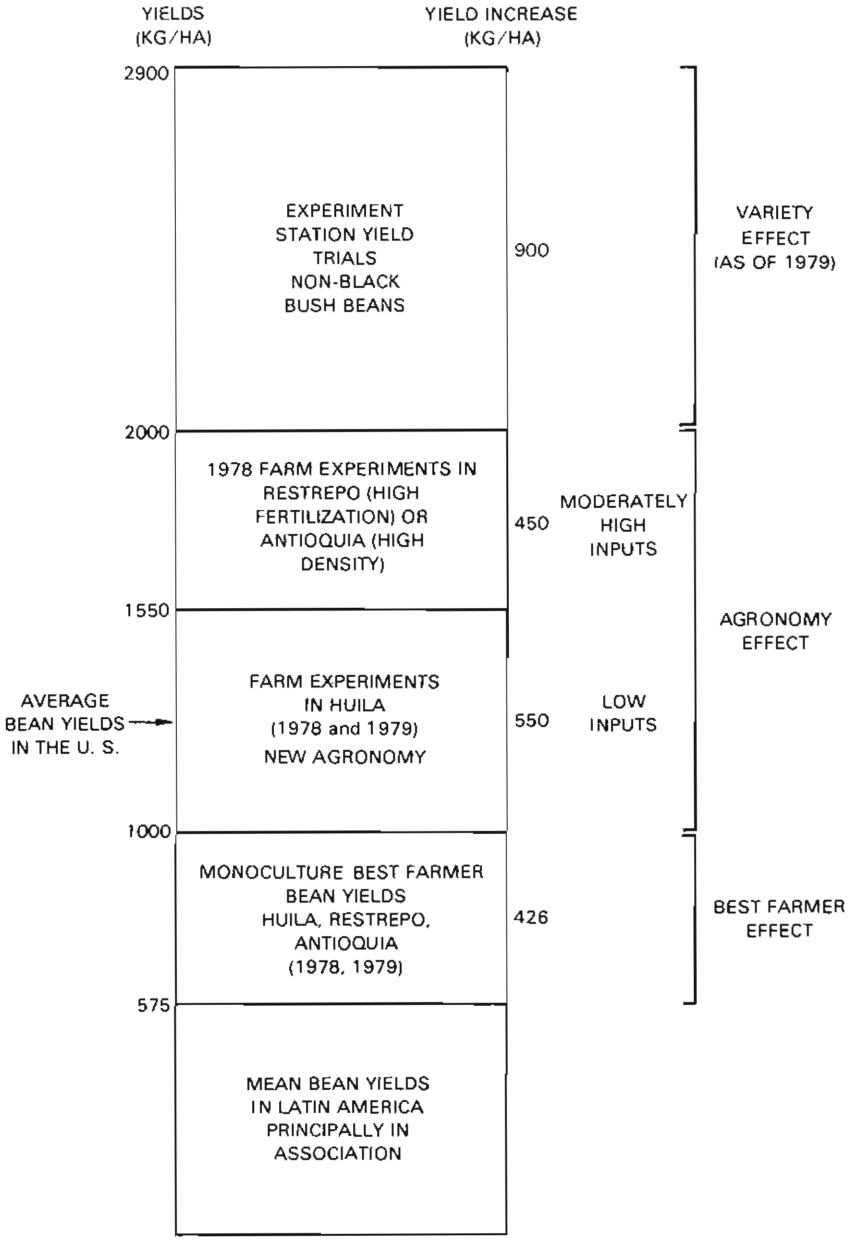

Figure 16. *Bean yields in farmers' fields, farm experiments and on the experiment station, 1978 and 1979, Colombia.*

Future Plans and Program Projections

Starting in 1979 all breeding lines being released for international testing are resistant to BCMV, and in 1981 all lines for areas in which anthracnose is a limiting factor will have resistance to this disease. Gradual improvement will continue for resistance/tolerance to the leafhopper, angular leaf spot, common bacterial blight, bean golden mosaic virus and other diseases and pests. It is probable that resistances to other diseases such as Ascochyta, root rots, web blight and nematodes will become more important selection criteria once resistance to priority diseases becomes more frequent. For particular diseases such as rust, with its large race variability, the stability of current resistance sources will determine whether greater efforts will be necessary in seeking more stable resistance, possibly in collaboration with Title XII research funding in the U.S.A.

To the moment yield potential has been less emphasized than yield stability. Even so some significant gains have been made in yield levels, and great variation in plant architecture and yield components demonstrated. Thus, though crosses for enhanced yield potential currently contribute only a low percent of total crosses, greater emphasis will be given to this area in the future. Also limited crosses will be made to develop improved snap bean cultivars.

An expanded effort in the search for increased tolerance to adverse conditions such as drought, low phosphorus and acid soils will make new materials more relevant to the principal production zones in Brazil, Latin America's largest producer of beans. Similarly, protein content and cooking time will receive increased attention in selecting breeding lines. While the 1979 IBYAN still lacked lines with proper seed sizes and colors, each year materials with a maximum number of resistances appropriate to their respective target zones will be approaching the seed characteristic requirements of national programs.

Working with several national programs, the Bean Program will expand its utilization of farm trials as feedback mechanisms to determine constraints on introducing improved varieties and associated technology. In this respect, farm trials will increasingly complement the IBYAN.

The size of national bean programs varies from a few scientists to large multidisciplinary teams. Therefore, the Bean Program will maintain its present disciplinary mix, as some national programs will need finished varieties, while others request parental sources or segregating populations. The latter, for example, should become increasingly important as a consequence of CIAT's training efforts. National program personnel will be able to increasingly manage and fine-tune the new germplasm and explore local adaptation and meet specific production problems and consumer preferences in their regions. To further strengthen this, regional outposted staff will be stationed in major bean production regions. In the future, IBYANs will contain an increasing number of locally improved materials.

Once initial research objectives have been met, a change in emphasis will occur as the Bean Program moves towards cropping systems research. This will enable the bean crop to fit better into existing cropping patterns and, where necessary, provide for improvement of cropping systems.

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