IDENTIFICATION AND STABILITY ANALYSIS OF TRAITS IMPORTANT TO YIELD OF BEANS IN ASSOCIATED CULTURE

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This is to certify that the

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ABSTRACT

IDENTIFICATION AND STABILITY ANALYSIS OF TRAITS
IMPORTANT TO YIELD OF BEANS IN ASSOCIATED CULTURE

By

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The identification of the traits in beans, which when grown in association with maize promote to the greatest practicable extent the potential for yield, was studied in 18 bean cultivars grown in monoculture and associated culture.

The qualitative effects of 17 traits upon certain parameters of adaptation were determined in each cultivar grown in six different cultural environments at two locations in Colombia, South America. The cultural environments were determined by location, crop system and maize type. These parameters were slightly different from those proposed by Finlay and Wilkinson (1963) because our purpose was to remove the geographic location effect and consider only the environmental effect produced by the different cultural systems. The two statistics used, the variety mean and the environment mean, were adjusted by division by the location mean.

It was considered that varieties are best adapted when the regressions of variety scores upon the respective environmental indexes approach unity, and had high mean values for the character under consideration. A variety with a regression coefficient of zero or approaching zero was considered to be stable.

A multiple regression analysis was carried out for each cultural system with yield as the response variable and the yield components as

independent variable in the first case and the individual yield components as response variables and plant morphological traits as independent variables in the second case.

In terms of the two adaptation measures, variation appeared to be higher in the least complex traits in a developmental and a genetic sense and lower in the more complex traits suggesting adaptation stability increased with an increase in the complexity of the trait.

Growth habit was the major varietal characteristic that determined varietal performance in almost all cultural environments. Varieties of Type I were stable ($b \to 0$) for cultural environmental changes. Type II varieties appear to be adapted to cultural environmental changes ($b \to 1$) and varieties of Type III and IV have differential responses to cultural environment changes ($b \gtrless 1$).

Some varieties that were high yielding in monoculture were also high yielding in associations, but in general, varieties high yielding in monoculture tended to be low yielding in associations and varieties low yielding in monoculture, tended to be high yielding in associations. This suggests that a variety cannot be selected for yield in the monoculture system to be grown in the association system. It should be noted, however, that only in one case (Variety Guatemala #594) was the regression value significantly different from unity.

From results of the multiple regression analysis, it was concluded that number of racemes, plant height, hypocotyl diameter and leaf dry weight were important to the determination of yield through the determination of yield components for the association of bean and short maize, but number of branches and days to maturity had contrasting values for yield components. Stem dry weight and leaf area had negative effects upon yield. The traits hypocotyl diameter, days to maturity and plant height were important in the determination of yield components in the association of bean and tall maize, but leaf dry weight, number of racemes and leaf area had contrasting values for yield components. Days to first flower and number of branches had negative effects upon yield. This suggests that plant breeders will have to make compromises in their decisions concerning the best set of traits in any given cultural environment.

Variety 5 (Guatemala #109-1-1), with good general adaptability for yield, capable of producing high yields in all the cultural environments considered in the present study, also showed regression values near unity for most of the morphological traits measured. In extrapolation from this example, it may be postulated that for a variety to be widely adapted to mixed cultural environments it should show good adaptation for most of the morphological traits important in yield determination.

Variety 1 (Rabia el Gato, also from Guatemala) was the least well-adapted variety with respect to yield. Interestingly, none of the morphological traits showed regression slopes close to unity, all being below one and most near zero. This case was the converse of the situation with Variety 5 but was consistent with the postulate arrived at on the evidence of Variety 5 and tends to reinforce that postulate.

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INTRODUCTION

Beans (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.) are the most important annual plants cultivated in mixed cropping systems by small farmers of Latin America. Much of the agricultural research, however, has been directed toward persuading the farmer to change to monocultural systems despite his reluctance to do so. The basis of pressing such changes has not been adequately researched and there is some evidence that in certain circumstances, mixed culture systems yield more per unit area than monoculture.

Furthermore, most research concerned with mixed cropping has been conducted with varieties selected for performance in monoculture. However, Francis *et al*. (1964) have stressed that varieties that are expected to perform in mixed cropping should be bred specifically for that purpose.

Variety by system interactions suggest that emphasis should be placed upon developing varieties which can be used across a wide range of the most common cropping systems in a region. Selection should be directed toward varietal characteristics which increase production of the mixed crop.

Plant breeders have made no decisive breakthroughs in yields of dry beans with the exception of developing a few disease resistant varieties which allow genetic potential to be expressed. This is especially true in Latin America where most dry bean production takes place in small plots dispersed over the countryside, including the higher elevations. In recent years, breeders have approached the low yield problem by considering the development of plant ideotypes for dry beans such as the ideotype suggested by Adams (1973) for monoculture.

Since the ideotype is in part a function of the production system, it seems obvious that the ideotypes proposed to increase bean yields in monoculture are not necessarily applicable to the environment and mixed cropping methods of the small farmer of the temperate tropics.

Little is known of the factors that condition adaptation in beans when grown in association with corn, and more research in this field is needed to identify traits that may contribute to a successful ideotype. The main objectives of this thesis are to determine the architectural and growth parameters of beans,which, when grown in association with corn, promote, to the greatest practicable extent, the potential for yield in any given environment.

The hypothesis to be tested is: bean plants, when grown in association with corn, have specific traits which act as stability parameters conferring to the bean plant a similar response to different environments.

LITERATURE REVIEW

Cutting across most agricultural systems of the tropics is the phenomenon of mixed cropping, a dominant characteristic of the humid and temperate areas. Mixed cropping, the conscious and deliberate cultivation of more than one type of plant in one field at the same time, is pantropical and long standing.

Beans and maize are the most important short-term annual crops cultivated in mixed cropping systems by small farmers of Latin America. Medina (1972) reported 80 percent of bean production in Brazil as coming from association primarily with maize but also with potato, cotton, oil palm, cassava, sugarcane, tobacco and coffee in lesser proportion. Similarly, Gutierrez et al. (1975) reported 90 percent in Colombia and 73 percent in Guatemala.

The way non-legumes are benefitted by association with legumes was studied by Virtanen et al. (1937). They concluded that nodules of the legumes exude nitrogen compounds as amino-acids which are utilized by the non-legumes. The utilization of these compounds are not always the same because non-legumes may vary in their ability to take up or utilize these exudates, and because the legumes themselves can differ in their capacity to exude nitrogen.

Experiments to compare maize in pure stand and associated with legumes have shown that the maize yield either was not affected by the association (Singh and Chand, 1969) or a modest reduction in the yield of maize was offset by production from the other crops (Agboola and

Fayami, 1971; Enyi, 1972). Kurtz et al. (1952) reported a yield decrease of 15 percent in maize grown in association with legumes as compared to monocultured maize.

Lugo-Lopez et al. (1953) reported no effect of beans on the production of sugarcane when both crops were cultivated in a mixed cropping system. A similar result was reported by Krutman (1968).

Mancini and Castillo (1960) suggested that as bean height increased the maize yield decreased, however, there was no relation between bean height and bean yield. Lepiz (1971) and Sixto (1975) reported a similar relation between bean height and maize yield but there was a negative relation between bean yield and maize density.

Francis et al. (1976), in 20 trials designed to study the bean-maize monocrop and mixed cropping systems, reported yield increases in bean and maize monoculture as a function of increased densities. There was apparently no interaction of bean density with cropping systems at the same optimum bean density and maize yields were not affected by the bean association. They concluded that simultaneous planting should be recommended for mixed cropping of bean and maize, but they suggested that Type II bean (bush type with small guide) should be planted one week ahead of the maize. They also reported a decrease in lodging of maize and a reduction of armyworm attack in the mixed cropping system as compared to the monocrop of maize.

Willey and Asiru (1972) found in mixed cropping of maize and bean, that in both species, intraspecific competition was more important than interspecific competition. They suggested that the two species were not competing for exactly the same parts of the environment. They reported that yield per plant decreased in all instances as plant population increased. The maize was found to have the higher relative competitive ability and this increased with increase in plant population pressure.

Hart (1975a), studying monocropping and mixed cropping systems involving bean, corn and manioc, found that the effects of fertilizer and weeding treatments on the yield of these crops were not the same for each cropping system. When fertilizer was applied in the mixed cropping system, corn yield increased and bean yield decreased. Interspecific competition, when all crops were planted at the same time, resulted in a dynamic interaction between bean and corn yield. Hart (1975b), in an economic analysis of his experiment, found that yield and economic return when all crops were planted at the same time, were 37 and 54 percent higher, respectively, than from the monocropping system.

Enyi (loc. cit.) reported a reduction in height and leaf area index (LAI) in maize when associated with beans. Alvim and Alvim (1969) concluded that when beans and maize were grown as mixed crops, the rates of productivity of the stands were usually higher than the means for the two crops grown singly. This indicates that the decrease in assimilation rate of bean due to shading by maize was outweighed by the increase in assimilation rate of maize as a result of reduced selfshading in the mixed stands. They found that in all densities studied, beans showed only about one third of the productivity and photosynthetic efficiency of maize.

All of these studies in mixed cropping of bean and corn have the same tendency in economic term: a higher economic return in the mixed cropping as compared to monocropping. The studies reported by CIMMYT (1972), CIAT (1975) and Basan _et al_. (1975) provide further support of this conclusion.

In order to understand the significance of environmentally induced changes, it is perhaps logical to turn to basic causes of such changes and details of the mechanisms involved. Bradshaw (1965) expressed the view that these variations are due to phenotypic plasticity. The degree of plasticity shown by a character can be related to the basic pattern of its developmental pathway. Stebbins (1950) has argued that characters formed through long periods of meristematic activity (such as over-all size, leaf number, etc.) will be more subject to environmental influences and are likely to be more plastic than characters formed rapidly such as reproductive structures. This argument can be supported by evidence of the differences in plasticity shown by different characters in *Achillea* and *Potentilla* in the experiments of Clausen *et al*. (1948). The contrast in the manner by which plants of determinate and indeterminate growth type react to density, provides further evidence. Species of indeterminate growth such as *Vicia faba* tend to respond to density by the number of parts formed, whereas, species of determinate growth such as *Helianthus annuus* tend to respond by changes in the size of the parts (Harper, 1961).

Beans have been classified into two main growth habit types; determinate type (shoot apex terminates in reproductive bud) and indeterminate type (shoot apex terminates in vegetative bud). Determinate bean plants have a poor competitive ability. The sprawling indeterminate type seems to compete quite aggressively. Vining indeterminate cultivars are usually less sensitive to changes in plant population than determinate bush type (Burke and Nelson, 1965; Leakey, 1972).

Hess (1960) reported extreme effects of environment on stem, internode length, number of racemes, number of branches and plant stiffness. He felt that these morphological characteristics which contribute to plant habit were quantitatively inherited. David and Frazier (1966) noted that a more sprawling habit was produced by warm weather but under cool conditions plants were short and sturdy. Photoperiod and temperature have been shown to influence flowering time and growth habit of determinate plant types depending on the genotype and combination of environmental factors (Coyne, 1966, 1970).

Emerson (1916) reported a simple 3:1 ratio in the F_2 generation for the growth habit character in beans. The allele for indeterminate was dominant to the allele for determinate type. The same result was reported by Miranda (1966). Bliss (1971) studied the inheritance of growth habit and flowering time in seven bean cultivars. He confirmed that indeterminate plant types were dominant over determinate and controlled by either a single gene or by two epistatic genes. He also found a linkage between time of flowering and determinate type. The same linkage was reported by Coyne and Schuster (1974).

Davis (1963) indicated that the net effect of the genes conditioning the expression of gross habit of growth, number of central stem internodes and height of pod attachment was largely additive, but the expression of plant height, length and mean internode length was a nonadditive since heterosis was observed for these characters; this work considered only determinate types. By differences in habit he was referring to sprawling versus erect types. In this paper, he reported that the height of pod attachment was highly dependent upon the number of central stem internodes.

Davis and Frazier (loc. cit.) reported that in crossing two determinate types, the genes conditioning the expression of erect growth habit, plant height and number of internodes were on the average recessive. They found that habit *per se* was continuously variable and that additive effects were predominant in the net effect of gene action on growth habit expression in determinate types even though upright habit was recessive to sprawling growth habit. Bliss (loc. cit.) concluded that sprawling growth habit was completely dominant and controlled by a single gene.

Duarte (1961) found complete dominance for high leaflet number indicating a simple genetic system for this trait. Leaf size was influenced by an additive genetic system.

The importance of genotype-environment interaction reflects the necessity of evaluating genotypes in more than a single environment. The plant breeder must consider the genotype-environmental interaction in the selection of superior genotypes. Johnson et al. (1955) emphasized the importance of this interaction and its effects upon selection in soybeans. Allard and Bradshaw (1964) reviewed previous work emphasizing the importance of interactions, particularly varieties-years, to plant breeders.

Yates and Cochran (1938) subdivided the genotype-environment interaction into linear and non-linear partitions. Plaisted and Peterson (1959) estimated adaptation in nine potato varieties by the interaction component for each possible combination between pairs of varieties. The mean of these estimates allowed them to determine the relative stability of each variety. Plaisted (1960) proposed an alternative method to determine stability in potato by omitting each variety from the analysis of variance and estimating its contribution to the total interaction when all varieties were included in the analysis. The larger the contribution of a variety to the interaction, the smaller will be its stability.

An analysis to identify stable genotypes has been worked out by Finlay and Wilkinson (1963) in barley. For each variety, a linear regression of individual yield on the mean yield of all varieties for each site in each season was computed. The regression procedure was used to describe the adaptation response of individual varieties to the range of environments in which they were grown and to assess a population of varieties for adaptation and yield performance. They used the location mean as a measure of the environments. Because the individual variety yields are plotted against the mean of all the variety yields, the population mean will have a regression coefficient of 1.0. Regression coefficients approximating 1.0 indicate average stability. When this is associated with high mean yield, varieties have general adaptability; when associated with low mean yield, varieties are poorly adapted to all the environments.

Eberhart and Russell (1966) discussed genotype-environment interactions and their importance in the development of improved varieties. They suggested that if the ability to show a minimum of interaction with the environment (or stability of performance) is a genetic characteristic, then we should do preliminary evaluation to identify the stable genotypes. In their model, they used in addition to the Finlay and Wilkinson parameter, the sum of squared deviations from regression as a second parameter to estimate stability.

The Finlay and Wilkinson method of stability analysis has been used by Rowe and Andrews (1964) with corn, suggesting that differences in stability among genotypic groups were associated with differences in ability to exploit favorable environments. The more vigorous heterozygous groups were capable of high performance under favorable conditions and were disproportionately reduced by unfavorable environments.

Scott (1967), from his results, indicated that selecting for yield stability in maize was effective.

Camacho (1968) estimated the yield stability of 26 homozygous bean lines for seven seasons at the same location by the use of variety x season interaction from the analysis of variance and the regression coefficient of variety means on the environmental index. Some genotypes showed adaptation to the unfavorable conditions of the first planting season.

Silvera (1974) suggested that genotypes with determinate habit, early maturity and the small leaved characteristics are responsible for wide adaptation in bean. His results were derived from seven varieties and 55 lines derived from crosses and backcrosses between these seven varieties and selected for different combinations of the characteristics named above.

Donald (1968) emphasized that a plant ideotype must be a poor competitor. This break from traditional thinking comes from the understanding that the individual plant within a community will express its potential for yield most fully if it suffers a minimum of interference or competition from its neighbors. The crop ideotype is expected to make a minimum demand on resources per unit of dry matter produced, but the community as a whole must draw on the total resources to a maximum.

Adams (1973) mentioned the isogenic line, model building and factor analysis as three methods that had been used in construction of plant ideotypes. There are numerous examples of the use of isogenic lines in genetic and breeding studies. The model building method was used by Vogel (1963) in wheat, suggested by Jennings (1964) for rice, and it is similar to the ideotype suggested by Donald (loc. cit.) for cereal and by Meck and Pearce (1975) for maize. Factor analysis was used by Morishima et al. (1967) in rice, Walton (1972) in spring wheat and by Denis (1971) in beans.

Adams (loc. cit.) suggested that no major changes need to be made to the bean ideotype proposed by him for monoculture in the morphological plant characterization in order for the type to be a successful competitor when grown in mixed culture with maize except to keep the leaf size medium to small and increase the sink capacity by raising the number of flowers per raceme and number of seeds per pod. On the physiological side, he suggested it would be desirable to raise the net rate of CO_2 exchange, increase the rate of translocation of photosynthate to sink and select for a high harvest index.

Tanaka (1974) suggested an indeterminate bean type which would produce many pods on the main stem for mixed culture with maize. Francis et al. (1975) mentioned some plant characters that had been reported in the literature as beneficial for mixed cropping systems; these are, photoperiod insensitivity, early maturity, non-lodging and population responsiveness.

MATERIALS AND METHODS

The field experiments were conducted in three sites representing different temperature, rainfall and soil conditions (Tables 1 and 2). These sites were:

1. Jalpatagua, Guatemala (14^{o} 08' N. Lat., 557 meters elevation, 26^{o} C mean annual temperature and 1360 mm annual rainfall)
2. Popayan, Colombia (02^{o} 42' N. Lat., 1600 meters elevation, 20^{o} C mean annual temperature, 1600 mm annual rainfall)
3. Palmira, Colombia (03^{o} 22' N. Lat., 1000 meters elevation, 23.9^{o} C mean annual temperature, 1000 mm annual rainfall)

Crop species used in the experiments were beans (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.). Eleven bean varieties were selected from the Guatemala bean collection, six bean varieties from the Centro International de Agricultura Tropical (CIAT) bean collection and one bean variety from Michigan, USA on the basis of contrasting values for plant height, flowering time, leaf area and the yield components, namely the number of pods per plant (X), number of seed per pod (Y) and seed weight (Z) (Table 3). Maize selection was based on plant height. In each location, adapted short and tall maize varieties were used (Table 4).

The criteria used to describe environments included location, crop system, maize type and planting pattern. Eleven different environments were studied (Table 5).

Table 1. Monthly mean temperature and total monthly rainfall per location during experiment work.

Month-Year	Temperature ^{o}C			Rainfall (mm)		
	Jalpatagua	Popayan	Palmira	Jalpatagua	Popayan	Palmira
Sep. 75	24.5			265.6		
Oct. 75	24.9			213.9		
Nov. 75	23.1			6.0		
March 76		18.1	22.7		306.0	74.3
April 76		17.2	24.3		164.8	82.8
May 76		17.9	23.8		80.6	82.2
June 76		18.3	24.2		52.5	12.6
July 76		19.0			0.5	

Table 2. Soil analysis per location.

Location	% O.M.	pH	ppm Phosphorus BRAY II	Meg/100 g of soil		
				K	Ca	Mg
Jalpatagua		6.7	26.0	0.55	11.4	4.0
Popayan	10.5	4.8	6.8	0.45	1.5	0.6
Palmira	4.2	7.9	49.0	0.77	27.4	15.8

Table 3. Characteristics of the bean selections.*

Entry	Variety	Origin	Plant height (cm)	Days to first flower	Leaf area dm^2/ plant	Number of pods/ plant	Number of seeds/ pod	Seed weight 100 seeds	Growth habit type+
1	Rabia el Gato	Guatemala	60.8	32	12.92	11.9	5.6	20.2	I
2	73 vul 8259	Colombia	132.1	44	16.56	15.9	6.6	21.7	III
3	Guate-067	Guatemala	98.9	41	22.16	18.3	5.7	20.0	II
4	Turrialba-21	Costa Rica	102.5	42	22.99	17.0	5.4	21.5	II
5	109-1-1	Guatemala	84.2	43	22.62	12.4	6.3	21.4	II
6	388-3-1	Guatemala	102.0	42	22.58	17.1	5.6	20.2	II
7	95-2-1	Guatemala	88.5	32	16.36	16.0	5.7	23.3	II
8	72 vul 21069	Colombia	102.6	43	24.75	15.1	6.0	22.0	II
9	Trujillo-3	Colombia	180.2	50	21.61	16.4	6.7	19.1	IV
10	Guate-367	Guatemala	105.8	41	17.77	15.5	5.9	21.3	II
11	Guate-594	Guatemala	125.8	44	14.25	20.3	5.3	25.6	III
12	Atlas	United States	82.3	34	14.13	11.9	5.4	17.3	II
13	Pompadour	Dominican Republic	46.0	35	17.80	8.7	4.6	47.3	I
14	Porrillo Sintetico	El Salvador	102.4	41	17.72	8.3	5.8	22.4	II
15	Jamapa	Venezuela	73.0	42	25.24	13.8	5.8	19.8	II
16	Puebla-152	Mexico	119.3	45	15.93	14.1	5.7	28.5	III
17	P-589	Colombia	202.1	50	29.62	14.4	7.2	21.8	IV
18	Sangre Toro	Colombia	338.3	60	56.09	2.5	5.3	50.0	IV

* Based on monocrop mean at Palmira location.

\+ I = determinate, bush; II = indeterminate, short guide; III = indeterminate, long guide; IV = indeterminate, climbing

Table 4. Characteristics of maize selections.

Entry	Variety	Origin	Days to flower	Days to harvest	Height at flowering (cm)
1	Piñoleño	Guatemala	73	140	190
2	ICTA Tropical-101	Guatemala	90	160	175
3	ETO-351	Colombia	90	160	160
4	Regional Yucatan	Colombia	120	200	260
5	H-210	Colombia	70	140	190
6	H-207	Colombia	63	140	290

Table 5. Environment classification.

Environment	Location	Crop system	Maize type	Planting pattern		Density (pl/ha)	
				Bean row	Maize row	Bean	Maize
1	Jalpatagua	Monocropping		1		222,222	
2	"	Mixed cropping	Short	2	1	148,148	41,667
3	"	" "	Short	3	1	166,665	31,312
4	"	" "	Tall	2	1	148,148	41,667
5	"	" "	Tall	3	1	166,665	31,312
6	Popayan	Monocropping		1		250,000	
7	"	Mixed cropping	Short	2	1	250,000	40,000
8	"	" "	Tall	2	1	250,000	40,000
9	Palmira	Monocropping		1		250,000	40,000
10	"	Mixed cropping	Short	2	1	250,000	40,000
11	"	" "	Tall	2	1	250,000	40,000

Bean varieties 1 to 12 were sown in environments 1 to 5 and varieties 1 to 18 in environments 6 to 11. Maize varieties were planted in eight different environments as follows:

Maize Varieties	Environment
Piñoleño	2, 3
ICTA Tropical-101	4, 5
ECTO-351	7
Regional Yucatan	8
H-210	10
H-207	11

A split plot experimental design with three replications was planted in each site: Jalpatagua in September, 1975; Popayan in March, 1976 and Palmira in March, 1976.

The planting method used in Jalpatagua was the same that farmers use, that is, using a diddle stick to sow bean and maize seeds. Three bean seeds were dropped in each hole, 30 cm apart and four maize seeds were dropped in each hole, 80 cm apart. Fifteen days after emergence, bean and maize plants were thinned to two and three plants per hill, respectively. The plot for environments 3 and 5 had 12 rows, 6 m long; the plot for environments 1, 2, 4 and 6 to 11 had 9 rows, 6 m long.

In Popayan and Palmira, a hand planting device was used for bean and maize and plants were thinned fifteen days after emergence leaving one bean and maize plant, 8 and 25 cm, respectively.

Fertilizer and pesticide were applied in all environments as needed for good crop development. Irrigation was applied in Palmira due to drought during the first and last stage of crop development.

In environments 1, 3 and 5, the three central bean rows of each plot were harvested, and in environments 2, 4 and 6 to 11, the two central rows of each plot were harvested.

The effect of the environment on bean variety performance was measured from data collected at the eleven environments. The following traits were recorded:

1. Flowering date: number of days from emergence to appearance of at least one flower on 50 percent of plants.
2. Number of branches: only those attached to the main stem were counted.
3. Number of nodes: nodes on branches and on the main stem were counted.
4. Number of racemes: racemes with one or more flowers were counted.
5. Hypocotyl diameter: measured below the cotyledonary leaves in cm.
6. Plant height: from the point where the main stem changes color (from brown to green) to the tip of the guide in cm.
7. Leaf area: calculated in dm^2 by:

$$\frac{\text{Sample leaf area (5 leaves) x Total leaf dry weight}}{\text{Sample leaf dry weight}}$$

8. Days to physiological maturity: number of days from emergence to appearance of 50 percent of pods turning yellow.
9. Leaf dry weight in g at flowering time.
10. Stem dry weight in g at flowering time.
11. Pod dry weight in g at flowering time.
12. Days to maturity: number of days from planting to harvest.
13. Yield: in units of 3.51 m^2 for environments 1, 3 and 5; 2.34 m^2 for environments 2 and 4, and 6 m^2 for environments 6 to 11. (In kilograms per hectare)

14. Number of pods per plant: pods with one or more seeds were counted.
15. Number of seeds per pod: seeds from 20 pods were counted.
16. Weight of 100 seeds: 200 seeds were weighed in g.
17. Canopy height: from the soil surface to the top of the plant canopy in cm.

Traits 1 to 7 and 8 to 10 were recorded at flowering time; traits 8 and 17 were recorded at physiological maturity and traits 11 to 16 were recorded at harvest time.

The following abbreviations have been used for traits measured in the various experiments.

AFFL = days to first flower
NB = number of branches
NN = number of nodes
NR = number of racemes
HD = hypocotyl diameter
PLH = plant height
LA = leaf area
DPHM = days to physiological maturity
LDW = leaf dry weight
SDW = stem dry weight
PDW = pod dry weight
DM = Days to maturity
Yield = yield of seed
X = number of pods per plant
Y = number of seeds per pod
Z = seed weight (gm/100 seeds)
CH = canopy height

At Palmira, the following traits were estimated for variety 18 based on data from Popayan: days to flowering time, days to physiological maturity, pod dry weight, days to maturity, yield, number of pods per plant, number of seeds per pod and weight of 100 seeds.

An analysis of variance for the split plot design was carried out for the 17 traits at each location. An analysis of adaptation for all genotypes was carried out according to the models of Finlay and Wilkinson and Eberhart and Russell with the data collected in environments 6 to 11.

Multiple regression (stepwise procedure, Draper and Smith, 1966) of yield against those variables that were considered important in the ideotype due to their stability was carried out for each environment to determine the relative importance of each variable in affecting yield.

The data were analyzed at the CIAT Computer Center, Michigan State University Computer Center and Wayne State University Computer Center.

RESULTS

Mean squares from the analyses of variance for the split-plot design used in all three locations are presented in Table 6. Each trait recorded was analyzed separately.

Cultural environments were not significantly different at Jalpatagua and Popayan for the 17 traits studied except for DM at Jalpatagua and PDW and Yield at Popayan. At Palmira, there were significant differences among environments for almost all the traits; the exceptions were DFFL, DPHM, DM, Y and Z.

Statistically significant differences occurred among the 11 genotypes at Jalpatagua and among the 18 genotypes compared at Popayan and Palmira for all traits.

The interaction cultural environments x varieties were not significant for the 17 traits at Jalpatagua. The traits NB, NN, DM, Yield and CH showed significant differences for the interaction effect at Popayan and the traits DFFL, LA, DPHM, LDW, DM, Yield, Z and CH showed significant differences for the interaction effect at Palmira.

The data recorded at Jalpatagua were considered unworthy of further analyses since there were no significant differences for environments and environments x varieties interaction effects for any of the traits.

A test for homogeneity of the variances across cultural environments was conducted for each trait at Popayan and Palmira. The variance for the traits PLH, DPHM and DM were significantly heterogeneous. Combined

Table 6. Mean squares for 17 traits measured on direct scales at three locations; Jalpatagua, Popayan, and Palmira.

Source of Variation	Degree of Freedom	DFFL	NB	NN	NR	HD	PLH	LA	DPHM
Jalpatagua									
Environments	4	0.4636	1.6797	35.1927	16.4058	0.0153	503.7664	85.6275	22.5545
Varieties	10	110.2000**	6.6219**	113.6510**	66.1773**	0.0196**	5037.1305**	83.0235**	227.0848**
Environments x Varieties	40	0.7303	0.3695	5.0023	4.0695	0.0016	73.8179	15.7996	1.2045
Popayan									
Environments	2	0.3024	0.2363	5.2063	14.3276	0.0002	2372.95	16.3819	7.5740
Varieties	17	407.3264**	5.1071**	173.4124**	74.8794**	0.0227**	12850.08**	35.9867**	946.2254**
Environments x Varieties	34	1.1782	0.3488*	16.3594*	5.7130	0.0048	3330.38	16.1415	10.8616
Palmira									
Environments	2	1.0556	3.8936*	377.82**	119.83**	.0542*	1143.90*	249.07**	9.6358
Varieties	17	405.7298**	2.7452**	707.62**	67.46**	.0329**	37948.03**	503.64**	662.7121**
Environments x Varieties	34	3.3039**	0.1319	15.08	7.99	.0022	134.66	20.87*	2.7142**

Table 6 (cont'd.)

Source of Variation	Degree of Freedom	LDW	SDW	PDW	DM	Yield	X	Y	Z	CH
<u>Jalpatagua</u>										
Environments	4	5.2548	8.0394	11.2272	8.4818**	616109	10.0431	0.1838	2.2635	73.7363
Varieties	10	5.5184**	9.7236**	25.7830**	438.2436**	549272**	10.6354**	3.2111**	84.5131**	173.0103**
Environments x Varieties	40	0.6188	1.0531	4.1378	0.9951	68795	1.7318	0.1308	0.8148	15.5584
<u>Popayan</u>										
Environments	2	0.8436	0.7246	147.3129**	2.888	475070**	46.3750	1.7400	1.2020	107.8209
Varieties	17	4.3243**	4.4164**	59.5899**	1019.2189**	93641**	78.7383**	1.9346**	988.8169**	1795.8852**
Environments x Varieties	34	0.7207	0.6896	12.6544	15.9411*	16958*	12.9656	0.3931	6.0856	238.1543**
<u>Palmira</u>										
Environments	2	32.6200**	32.6279**	1272.93**	213.72	53731905**	654.98**	.8242	14.30	5268.89**
Varieties	17	23.2628**	28.8252**	85.01**	1285.68**	567028**	69.02**	3.4062**	634.19**	5678.62**
Environments x Varieties	34	1.0506*	0.7683	14.12	8.71**	182751**	8.06	.1846	3.78**	817.93**

* Significant at the 5% level
** Significant at the 1% level

analyses of variance for Popayan and Palmira were carried out for the traits that showed no significant heterogeneity (Table 7). The environments and varieties effects were significantly different for all traits except for DFFL which was not significant for the effects of cultural environments. The environments x varieties effect was significantly different only for DFFL, LDW, Yield, Z and CH in the combined analyses.

The environmental means and environmental indexes for cultural environments 6 to 11 are presented in Table 8. The environmental indexes were calculated by dividing the cultural environmental mean by the location mean. This index is slightly different from the Finlay and Wilkinson environmental index because our purpose was to remove the location effect and consider only the cultural environment effect produced by the different cultural systems, that is, beans in monoculture and beans associated with short and tall maize types.

A regression analysis of each variety mean, adjusted by division by the location mean against the environments indexes, was carried out for the 17 traits recorded (Table 9).

The significance of every regression coefficient was calculated with a t-test to identify those coefficients significantly different from the population b value of 1.0.

A coefficient at or near 1.0, associated with a large mean and a deviation mean square as small as possible (close to 0), are indicative of general adaptation (Eberhart and Russell, loc. cit. proposed the deviation mean square as a second parameter for stability. This parameter was not included in the present work because it was very close to 0 for all traits measured on each variety.) Regression coefficients significantly greater than 1.0 indicate below general adaptability or varieties

Table 7. Mean squares for 14 traits measured on direct scales at two locations; Popayan and Palmira.

Source	d.f.	DFFL	NB	NN	NR	HD	LA	LDW
Locations	1	7491.8642**	125.0669**	1379.7098**	29.7631*	.102898**	4455.07**	73.3687**
Replications (L)	4	2.0031	1.7754**	155.3732**	91.2928**	.013316**	212.23**	10.2246**
Environments	2	0.5308	2.9631**	231.5023**	105.0756**	.027358**	84.74**	19.9553**
Locations x Environments	2	0.8271	1.1667**	151.5243**	29.1291**	.026917**	180.72**	13.5083**
Replications (L) x Environments	8	1.8595	0.4477*	22.8694	5.6666	.002405	22.85	1.2480*
Varieties	17	786.1181**	5.8310**	660.7543**	119.6586**	.049164**	322.41**	17.1277**
Locations x Varieties	17	26.9361**	2.0213**	220.2782**	22.6784**	.006451**	217.21**	10.4594**
Environments x Varieties	34	2.1125**	0.2418	11.8755	5.6121	.002371	17.91	0.9505*
Locations x Environments x Varieties	34	2.3696**	0.2389	19.4531*	8.0889	.004660	19.10**	0.8470
Residual	204	.9891	0.2049	12.3099	5.1295	.002393	12.09	0.6496
Total	323							

Table 7 (cont'd.)

Source	d.f.	SDW	PDW	Yield	X	Y	Z	CH
Locations	1	148.0007**	792.1098**	1061798**	26.4081	33.0369**	142.8556**	71749**
Replications (L)	4	9.7378**	81.9457**	707094**	54.0824**	1.0695*	4.6136	879**
Environments	2	17.9430**	1079.4156**	3685043**	501.2874**	2.1697**	7.4180*	1935**
Locations x Environments	2	15.4086**	340.8320**	4669572**	200.1715**	0.3945	6.9383*	3440**
Replications (L) x Environments	8	2.2507**	37.3882**	358424**	22.5508**	0.4630	4.5837*	229**
Varieties	17	22.5085**	46.5083**	358942**	110.3501**	4.5603**	1581.1213**	5777**
Locations x Varieties	17	10.7331**	98.0970**	674017**	37.4098**	0.7805**	48.7453**	1696**
Environments x Varieties	34	0.6109	14.3803	107888**	9.7929	0.3214	4.8525**	768**
Locations x Environments x Varieties	34	0.8470	12.3897	115574**	11.2295*	0.2562	3.1447	287**
Residual	204	0.6496	21.2123	56604	7.4773	0.3651	2.1831	63
Total	323							

* Significant at the 5% level
** Significant at the 1% level

Table 8. Environmental means and environmental index from 18 varieties for 17 traits measured at six environments.

Environments	DFFL		NB		NN		NR		HD		PLH		LA		DPHM		LDW	
	Mean	Index	Mean	Index	Mean	Index	Mean	Index	Mean	Index	Mean	Index	Mean	Index	Mean	Index	Mean	Index
Popayan																		
6	52.37	1.0056	3.85	1.1027	20.19	1.0151	11.62	1.0355	0.5456	1.0000	58.86	1.0033	11.34	0.9727	88.01	0.9934	3.53	1.0181
7	51.91	0.9967	3.84	1.0007	10.91	1.0010	11.29	1.0063	0.5461	1.0009	59.81	1.0177	13.55	1.0561	88.59	1.0061	3.56	1.0247
8	51.97	0.9979	3.73	0.0980	10.57	0.9839	10.75	0.9582	0.5451	0.9991	57.53	0.0979	11.93	1.0022	87.56	0.9943	3.32	0.9573
Palmira																		
9	42.28	1.000	2.83	1.1050	27.03	1.1253	13.58	1.1612	0.5459	1.0704	119.51	0.9819	21.73	1.1247	51.17	1.0051	5.30	1.1972
10	42.42	1.0033	2.56	0.9995	22.96	0.9559	11.24	0.9612	0.4987	0.9778	118.62	0.9747	18.62	0.9640	50.55	0.9939	4.16	0.9388
11	42.14	0.9967	2.29	0.8955	22.07	0.9188	10.26	0.8776	0.4855	0.9520	126.99	1.0434	17.61	0.9113	50.95	1.0010	3.82	0.8829

Environments	SDW		PDW		DM		Yield		X		Y		Z		CH	
	Mean	Index	Mean	Index	Mean	Index	Mean	Index	Mean	Index	Mean	Index	Mean	Index	Mean	Index
Popayan																
6	3.21	0.999	10.16	1.1639	118.09	0.9995	1532	1.2295	10.17	1.0828	5.18	1.0317	22.79	1.0013	45.07	1.0102
7	3.33	1.0362	9.09	1.0408	117.99	0.9986	1267	1.0169	9.63	1.0260	5.06	1.0074	23.04	0.9984	45.74	1.0252
8	3.10	0.9639	6.94	0.7953	118.39	1.0020	940	0.7544	8.37	0.8911	4.83	0.9609	22.77	1.0003	43.04	0.9646
Palmira																
9	5.43	1.1872	17.38	1.4666	96.13	1.0242	2873	1.6352	13.87	1.3973	5.81	1.0252	24.63	1.0226	70.68	0.9572
10	4.37	0.9551	9.89	0.8346	92.42	0.9847	1338	0.7615	8.66	0.8722	5.61	0.9889	24.00	0.9963	65.25	0.8837
11	3.92	0.8577	8.28	0.6988	93.01	0.9910	1059	0.6027	7.25	0.7305	5.59	0.9860	23.63	0.9811	85.59	1.1591

Table 9. Means and regression coefficients of 17 traits measured for 18 varieties tested in six environments at two locations: Popayan and Palmira.

Var	DFFL Mean	DFFL b+	NB Mean	NB b	NN Mean	NN b	NR Mean	NR b	HD Mean	HD b	PLH Mean	PLH b	LA Mean	LA b	DPHM Mean	DPHM b
1	36.85	0.1273**	2.72	0.5397	15.10	0.2587**	11.18	0.7007	0.5050	-0.4363**	53.63	0.2306**	10.83	-0.3013**	62.83	-2.2946**
2	50.33	2.0552**	2.93	0.9854	20.22	1.1923	8.77	0.1666*	0.5238	0.8780*	91.53	3.9309**	13.95	-0.7467**	83.07	0.8594*
3	47.00	0.2208**	3.90	1.0069	22.03	1.2650	13.03	1.6254*	0.5933	1.2861*	68.73	0.8181	16.74	2.1959*	83.52	0.0113**
4	46.83	1.8770**	3.57	1.2172	20.32	0.7392*	11.88	0.9388	0.5438	1.3312*	75.28	0.4918**	16.57	1.7183*	81.23	1.3166**
5	47.33	4.6942**	3.52	1.1144	19.35	1.0848	11.20	1.0750	0.5742	2.2609**	68.12	0.1191**	16.94	1.8349*	82.35	0.9294
6	47.00	-1.5520**	3.57	1.3652*	20.32	0.7882**	11.55	1.0937	0.5523	1.3398**	72.98	0.9647	14.84	1.8858**	81.60	0.9884
7	37.22	1.0494	2.68	1.6195*	17.23	1.0176	11.97	1.2298	0.4680	1.2387**	68.53	0.2680**	12.59	0.6667**	66.53	-0.9304**
8	46.95	0.7438**	3.25	1.6760**	18.67	1.3129**	10.50	1.1250	0.5643	1.9269**	75.05	-0.4974**	17.84	1.7112**	82.15	2.6559**
9	52.60	-3.0838**	3.32	1.7367**	28.62	2.3580**	12.43	1.7831**	0.4877	1.3934**	126.53	0.4858**	15.79	0.3933*	89.28	2.1957**
10	45.72	-0.8641**	3.22	1.3549**	21.05	1.2185	11.38	1.5131	0.4980	1.2106**	80.78	2.0255**	13.88	0.7757	81.50	2.3690**
11	46.17	-1.1811**	3.08	-0.0951**	23.53	-0.7999**	12.82	-0.4836**	0.4695	-0.4794**	100.90	1.4678**	13.42	-0.5864**	81.50	-0.6900**
12	40.12	1.2456**	3.98	0.2908*	27.95	1.1210	18.60	0.8456	0.4003	0.6474**	69.53	0.5135	11.81	0.5477	78.05	1.9649**
13	38.10	0.5692**	2.53	1.2531	11.25	0.6523**	8.53	0.9798	0.5357	1.2357*	42.22	0.8945	10.78	1.0487	69.07	0.7557*
14	49.72	-1.9782**	3.52	1.1567	16.88	0.8912	8.57	0.6719**	0.6220	1.3083**	76.35	0.2573**	15.34	0.1604**	81.38	0.4857**
15	47.22	-0.8321**	3.80	-0.0586**	20.97	1.1216	12.62	1.4396	0.5767	1.1192	67.18	2.0762**	16.69	0.9606	81.00	0.2670**
16	48.45	0.1581**	3.37	1.7074*	28.18	1.6365*	13.78	1.3472	0.5235	0.6476**	93.32	0.5539**	14.79	0.3599	81.43	-1.4842**
17	56.15	-0.4400**	2.52	0.5602	25.67	0.8247	12.75	-0.2914**	0.5340	0.0903**	139.98	1.8861*	19.57	1.8557**	88.87	3.0365**
18	63.73	-1.9645**	1.80	0.5557	37.82	1.3119	6.50	0.1605*	0.5320	0.7759	253.53	1.5302**	29.76	3.4748	106.02	5.5655**

Var	LDW Mean	LDW b	SDW Mean	SDW b	PDW Mean	PDW b	DM Mean	DM b	Yield Mean	Yield b	X Mean	X b	Y Mean	Y b	Z Mean	Z b	CH Mean	CH b
1	2.92	0.0244**	2.355	0.4710*	7.79	0.4404*	91.08	0.5172**	1207	0.6026	8.80	0.7079	5.10	0.2899**	19.10	1.3480**	45.03	0.7230
2	3.79	0.1002*	3.307	0.2526**	10.40	1.3037	110.33	1.4217**	1437	1.1075	9.30	1.2178	5.82	1.1860*	20.17	0.8222**	66.08	0.9591
3	3.88	1.0271	3.910	1.0330	10.21	1.2134	105.62	1.9114**	1315	1.0315	11.80	1.5464*	5.42	1.1929*	18.45	1.7443**	54.12	0.7692
4	3.64	0.9256	3.930	0.9803	9.84	0.8755	104.55	1.2862**	1618	1.0640	11.27	1.1152	4.93	-0.6417**	20.18	1.2186**	53.42	0.4099*
5	4.11	1.2039	3.882	1.3983	10.71	0.7740	107.95	0.3272**	1986	1.1363	11.22	0.8062	5.68	0.0942**	19.82	0.5049**	47.87	1.1368
6	3.45	1.2431*	3.772	1.5016**	9.95	1.2404	104.90	0.5387**	1621	1.1191	11.18	1.3701	5.07	2.775**	19.38	-1.0255**	55.72	1.1577
7	3.41	0.5072**	2.417	0.5362**	11.64	0.9099	91.72	1.3233**	1626	0.8694	11.07	0.8997	5.52	0.8362*	20.85	1.7517**	45.45	0.1522**
8	3.85	1.3783*	3.575	1.3425	9.94	1.3885*	104.57	0.3447**	1492	1.1487	9.12	1.4022**	5.58	1.9371**	19.90	0.6517**	50.62	0.8062
9	3.93	1.4374	4.383	1.1399	11.42	1.0700	118.72	1.2630*	1323	0.8298	10.53	1.3842	5.88	0.4418**	19.67	-0.9093**	74.38	1.7160**
10	3.64	1.1150	3.522	1.0442	14.11	1.1476	106.82	0.0276**	1624	0.8898	12.38	1.2738	5.72	-0.8435**	23.18	-3.3286**	57.75	2.2216**
11	3.35	-0.1752**	3.803	-0.2088**	12.46	1.7278	106.43	0.8007**	1614	1.3852*	11.43	1.5340	4.87	2.8300**	24.63	0.7778**	65.55	0.8545
12	2.97	0.3959**	2.822	0.4648**	8.88	0.4078	102.77	2.7111**	1504	0.8202	12.17	0.6156	5.17	1.6429**	17.32	-0.7719**	45.18	1.0544
13	3.75	1.7127**	3.268	1.3940	8.57	0.8126	90.17	1.1257*	1400	0.8833	5.68	0.4511*	3.97	1.3709*	43.78	5.4429**	45.07	-0.1063**
14	4.03	0.8174	4.270	0.9464	8.55	0.4102**	105.37	0.5264**	1460	0.8833	7.13	0.3645**	5.58	0.5604**	19.95	1.7937**	60.22	1.5177*
15	3.88	1.4647**	3.955	1.0144	8.17	0.9429	102.98	2.0808**	1453	1.4001	10.00	1.0970	5.28	0.7564**	17.05	2.1898**	49.07	0.2079**
16	4.56	0.7086	4.618	1.0129	10.92	0.9728	109.23	2.0808**	1490	0.9665	9.15	1.1788*	5.17	2.1451**	25.38	-0.1832**	53.18	1.3694
17	4.46	1.9235**	4.742	2.0232*	11.77	1.0711	114.02	0.9801	1581	1.1692	9.08	0.7470	6.25	0.3540**	20.28	-0.1832**	77.45	1.2595
18	7.45	2.2553	7.490	1.6519	9.92	1.2842	135.02	-0.1138**	1276	0.8443	2.63	0.3044*	5.23	1.6614**	52.55	5.0941**	119.97	1.9196

* Significant at the 5% level
** Significant at the 1% level
\+ Regression coefficient

adapted primarily to high yielding environments. Coefficients significantly smaller than 1.0 indicate varieties that tend to perform at the same level in more favorable and less favorable environments. This is usually associated with a low mean since the varieties are not able to exploit favorable environments. Varieties with b-values at or near 0 were considered as stable. Varieties with large positive b-values are characteristic of genotypes that perform poorly in unfavorable conditions but that respond better than average as the environment improves. On the contrary, those varieties with large negative coefficients perform relatively better in poor environments.

Stability will be discussed initially in terms of individual traits. In this study, 17 traits were recorded.

Days to First Flower

The variety having a b-value for DFFL nearest to 1.0 was Variety 7 with b = 1.05. The lowest b-value, -3.08, was for Variety 9 and the highest, b = 4.69, was for Variety 6. All coefficients were significantly different from unity except for Variety 7. The lowest mean value of DFFL was 36.85 for Variety 1; the highest mean value was 63.73 for Variety 18. All varieties were relatively variable for DFFL except Variety 1, 3 and 16 (Table 9).

Days to Physiological Maturity

Varietal responses in DPHM to environmental changes were similar to those for DFFL. This could be expected because the traits are related. The b-values for DPHM of all varieties except 5 and 6, were significantly different from unity. The most stable varieties were 3, with b = 0.01 and 15,with b = .27. The lowest and highest means corresponded to Varieties 1 and 18 as in DFFL. But the closest b-value to 1.0 was for Variety 6,with b = .99 (Table 9). Variety 1 was negatively affected by environmental improvement for DPHM. This can be explained because the pod filling stage is a critical stage that is achieved in a short time when Variety 1 is associated with maize due to its early maturity and the maize competition.

Days to Maturity

The results for DM follow the same pattern found in DFFL and DPHM. All regression coefficients were significantly different from unity except for Variety 17 with b = .98. But DM was less variable than DFFL and DPHM. Varieties 10 and 18 were the most stable with b-values of 0.03 and -0.11, respectively. Days to maturity values for Variety 18 were similar because they were estimated at Palmira as the same values for the three cultural systems. We should look at Variety 18 with reserve for those traits that were estimated at Palmira.

Plant Height

Plant height was one of the most variable traits analyzed in the present study. It was highly affected by location. The homogeneity of variance test showed a highly significant difference for this trait. In the regression analysis, Varieties 3, 6, 12 and 13 did not show regression coefficients significantly different from unity; all, however, were below 1.0. Varieties 1 and 5 were more stable with b-values of 0.23 and 0.12, respectively (Table 9). Bean plants of Type I (Variety 1) or Type II (Variety 5) were generally stable. Bean plant Type III (Variety 2) or Type IV (Variety 18) were variable and highly affected by cultural environmental changes. The best environment for this trait was the high maize at Palmira.

Canopy Height

The trait CH was less variable than PLH. This was due to the fact that most bean plants tended to set bunches of leaves but the guide can or cannot continue growing depending upon the light. This trait was measured from the bottom to the top of the group of leaves that we consider represented canopy height. Environment 11, where the bean plant was supported by the maize plant, was the best environment for this trait. Varieties 7, Type I and 13 and 15, Type II, with b-values of 0.15, -0.12 and 0.21, respectively, were the most stable. The least adaptive variety was #10 with a b-value of 2.22 (Table 9). Variety 10 adapted to high altitude in Guatemala and had a strong positive response to environments 10 and 11 in terms of CH.

Leaf Dry Weight, Stem Dry Weight

Almost all varieties presented the same pattern for the traits LDW and SDW in terms of regression coefficients. Varieties 8, 13 and 15 with b-values of 1.38, 1.71 and 1.46, were significantly different from 1.0 for LDW but they were not significant for SDW. Their b-values were 1.34, 1.39 and 1.01, respectively. These values are very close to those found for LDW (Table 9). Variety 11 had the lowest b-values in both traits; -.17 for LDW and -.21 for SDW. The highest regression coefficients and means were for varieties 18 and 17 for both traits. Variety 11, Type III, which comes from the high elevation of Guatemala where it was selected for its adaptation to associated culture systems, appeared to be depressed when it was grown in monoculture because in more than half of the traits, it responded negatively to the monoculture system. Varieties 17 and 18 have growth habit Type IV. They had the best response to increase in LDW and SDW when they were grown in monoculture compared to the other varieties. Variety 2 which had growth habit Type II behaved in different ways. It was slightly variable in all environments for LDW and SDW. Almost all varieties with growth habit Type II, were affected positively by monoculture systems but they cluster with the population regression line in both traits. Variety 1 responded favorably to the monocultural system.

Pod Dry Weight

There was less variation among varietal regression coefficients for the trait PDW than was expressed for LDW and SDW. Only varieties 1, 8 and 14 had b-values significantly different from 1.0. Almost all of the regression lines clustered with the population mean responded positively to the more favorable environments. Varieties 1 and 11 departed from the population line and were not adapted to environmental changes, but Variety 1, Type I, was the most stable and Variety 11, Type III, was the least stable (Table 9).

Hypocotyl Diameter

For trait HD, two thirds of the varieties were well adapted to environmental changes. Varieties 1 and 11 were less adapted and responded negatively to environmental changes with b-values of -.44 and -.48, respectively. The negative response of Variety 11 to environment 9 is typical when this environment increases the trait under consideration. The most stable variety was 17 with b = .09 (Table 9).

Leaf Area

Varietal regression lines for LA departed from the population regression line in a disruptive pattern. Varieties 13 and 15 coincided most closely to the population mean value of b = 1.0, with b-values of 1.05 and .96, respectively. These two varieties were the most adapted to changes in cultural environments but their means were below the environmental mean in all environments (Table 9). These varieties were similar in that they had the capacity of flexibility in producing large leaves which made them adaptable to the improving environment. Variety 14, with small leaves, was the most stable, with b = .16. The highest means were for Variety 18 and 17 which were positively affected by the monoculture system as in LDW and SDW. Leaf dry weight and SDW were highly correlated with LA (r = 0.90). Variety 1 was relatively stable but responded negatively to an improved environment. Varieties 2 and 11, Type III, gave the same response as Variety 1. Figure 1 shows this response.

Number of Branches

The combined analyses of variance for NB (Table 7) showed significant differences between cultural environments. The regression coefficients varied from a low of -.09 to a high of 1.74. Departures from the mean of b = 1.0 were not as great as for LA. Some coefficients were significantly different from unity (Table 9). The highest mean value of NB was 3.98 for Variety 12 with a coefficient of b = .29. Variety 3 had the next highest mean of 3.90 and a regression coefficient of 1.01 showing general adaptation for this trait. The lowest mean value was 1.80 for Variety 18 with a b-value of .55 suggesting poor adaptation to all six environments. Varieties 4, 5, 6, 7, 8, 9, 10, 12 and 14, Type II, were below average in stability. Varieties 11 and 15 were the most stable with slight response to poor cultural environments (Figure 2).

Number of Nodes

The regression coefficients for NN varied from a low of -.80 to a high of 2.36. When the variety means were plotted against the environmental means, the points were not as uniformly distributed around the mean slope of 1.0 as they were in other traits (Figure 3).

Varieties 12, 17 and 18 clearly exceeded the population mean values in all cultural environments and showed positive slopes not significantly different from 1.0. Variety 11 produced fewer nodes as the cultural environments improved (b = -.80). Variety 9 behaved in the opposite manner, being relatively low in node number in the poor environments but very high in the favorable environments (b = 2.36).

Varieties 1 and 13, Type I, were less affected by environmental change than Varieties 11 and 16, Type III, or Varieties 9, 17 and 18, Type IV. Almost all regression lines for Type II varieties, cluster around the population regression line and appear to be more adapted in node number to environmental change than other varieties with different growth habits.

Number of Racemes

Varieties 4, 5, 6, 7, 8 and 10, all Type II, showed general adaptation for NR with linear regressions close to 1.0. These varieties were adapted to changes in cultural environments but some varieties with the same growth habit had means above all the environmental means such as Variety 12 and others below all the environmental means such as Variety 14 (Figure 4). Varieties of Type I, III and IV had different responses to environmental changes. Varieties 1 and 13, Type I, responded similarly to varieties of Type II. Variety 2, Type III, was stable but Variety 11, Type III was less stable and responded negatively as the environment improved. Variety 18, Type IV was stable with b = .16, but Variety 17, Type IV was less stable and responded negatively as the environment improved (b = -.29)

Yield

Yield was the trait in which almost all regression lines for all varieties clustered with the mean population regression line. Only the regression coefficient for Variety 11 was significantly different from unity. Variety 5, with the highest mean yield (1986 kg/ha) and a b-value of 1.14, showed excellent stability and general adaptation (Figure 5). Varieties 1 and 13, Type I, with b-values of .60 and .74 were the more stable but poorly adapted to changes in cultural environments. Variety 1 had the lowest mean value (1207 kg/ha).

The highest yielding variety for environments 6 and 8 was Variety 5, for environment 7, Variety 12 and for environments 9, 10 and 11, Variety 17.

Number of Pods Per Plant

The highest mean value of 12.38 was for Variety 10 with a regression coefficient of b = 1.27. The lowest mean value was 2.63 for Variety 18 with a coefficient of .30 indicating above average stability but poorly adapted to all six environments (Figure 6). When the coefficients were plotted against the mean slope of 1.0, the points were uniformly distributed around the mean slope. This distribution did not occur with the other components of yield.

Number of Seeds Per Pod

All regression coefficients for this trait were significantly different from unity. Variety 5, with a very low regression coefficient, b = .09, showed a high phenotypic stability. Figure 7 shows the advantage of Variety 5 in a poor environment. Varieties 4 and 10, Type II, produced fewer seeds per pod as the cultural environment improved (b = -.64 and b = 0.84, respectively). Variety 11, Type III, behaved in the opposite manner being relatively low in Y in the poor environments but high in the favorable environments (b = 2.83).

Seed Weight

Seed weight coefficients of regression for the different varieties were variable from a low of -3.33 for Variety 10 to a high of 5.44 for Variety 13. When the coefficients were plotted against the mean slope (Figure 9), the points were not as uniformly distributed around the mean slope of 1.0 as they were for the other components of yield. One-third of the varieties had negative coefficients indicating that as the cultural environment was conducive of high seed weight, these varieties produced lighter seeds. Figure 8 shows this response.

The variation of regression coefficient values around the mean slope, considering all varieties for yield and yield components, was largest for seed weight and smallest for yield (Figure 9). The regression coefficients between yield components (X, Y and Z) appeared to show a compensatory relationship. Variety 1, with b-values below the mean slope for X and Y, had b-values above the mean slope for Z. Variety 10, with b-values above the mean slope for X, had b-values below the mean slope for Y and Z. Varieties 13 and 18, with regression coefficients below the mean slope for X, had regression coefficients above the mean slope for Y and Z. Varieties 10, 11, 13 and 18 had the extreme b-values for X, Y and Z. Variety 1 was typical of the remaining varieties which had b-values close to the mean slope.

It should be noted that the ranges of environmental indexes for some traits were very narrow. The regression slopes, therefore, tend to suggest great diversity among the varieties in their stability responses to cultural environments. This is mostly an artifact of scale and should not be taken to reflect seriously one way or the

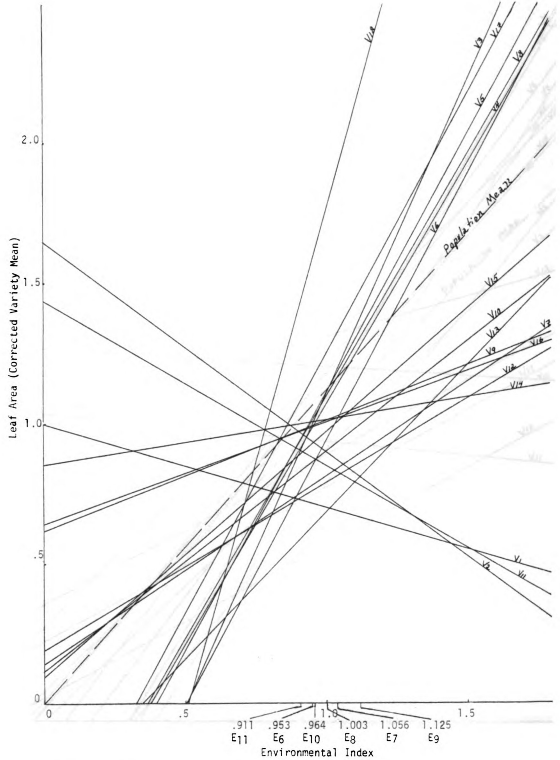


Figure 1. Regression lines showing the response (LA) of 18 varieties to six different cultural environments.

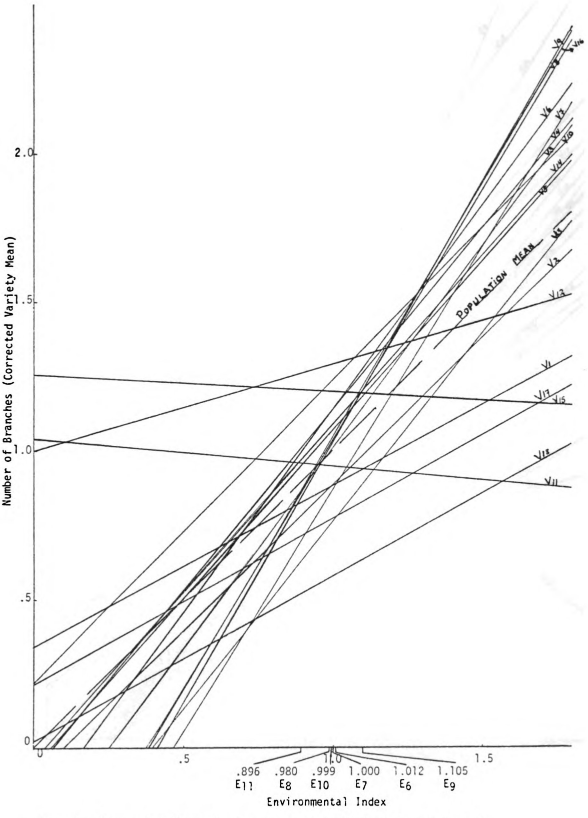


Figure 2. Regression lines showing the response (NB) of 18 varieties to six different cultural environments.

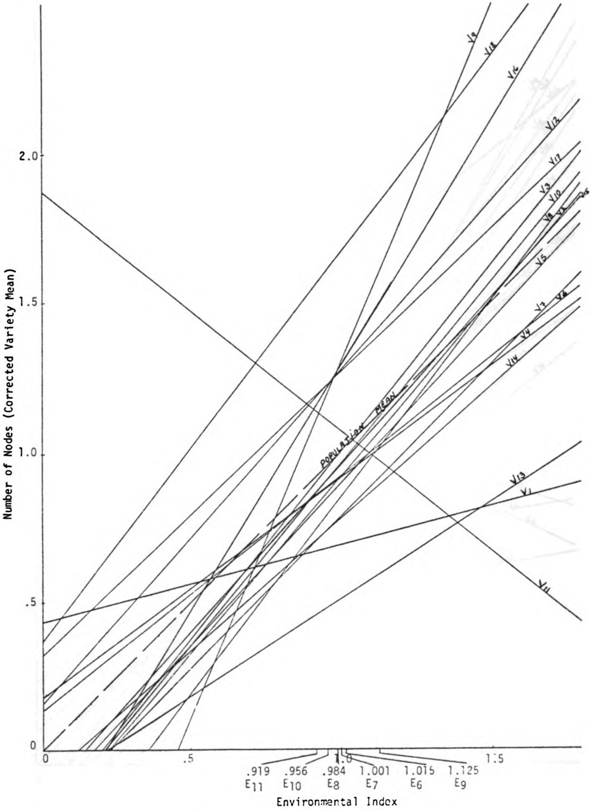


Figure 3. Regression lines showing the response of (NN) of 18 varieties to six different cultural environments.

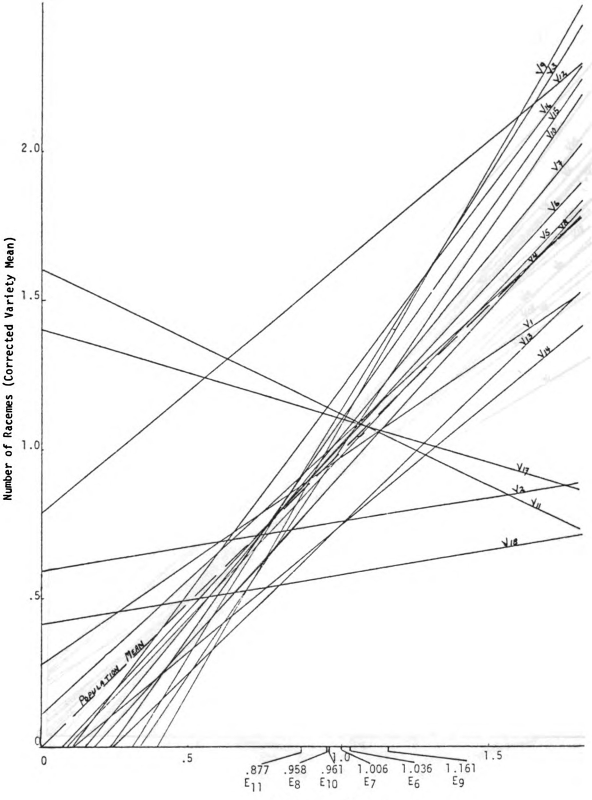


Figure 4. Regression lines showing the response (NR) of 18 varieties to six different cultural environments.

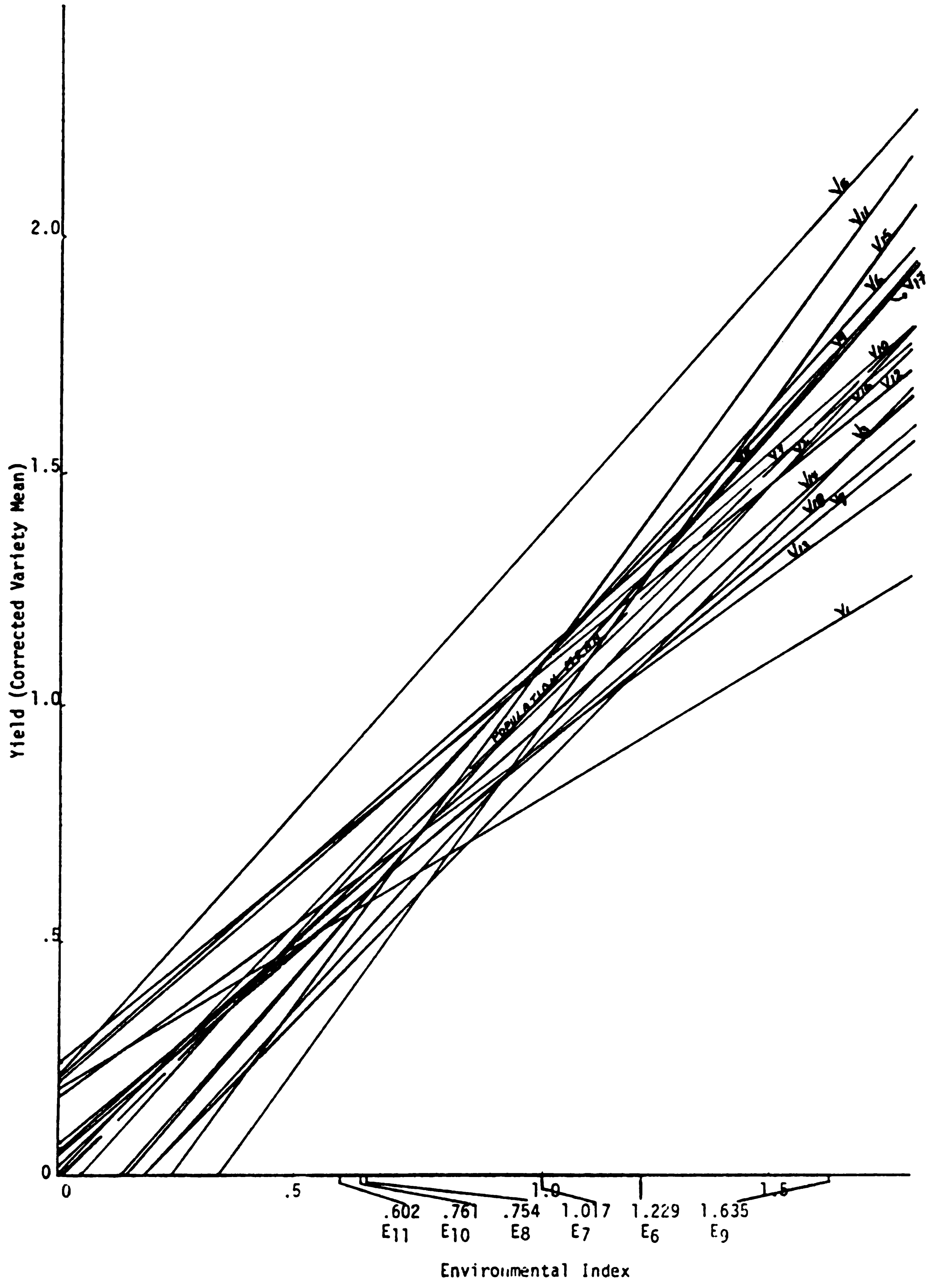


Figure 5. Regression lines showing the response (Yield) of 18 varieties to six different cultural environments.

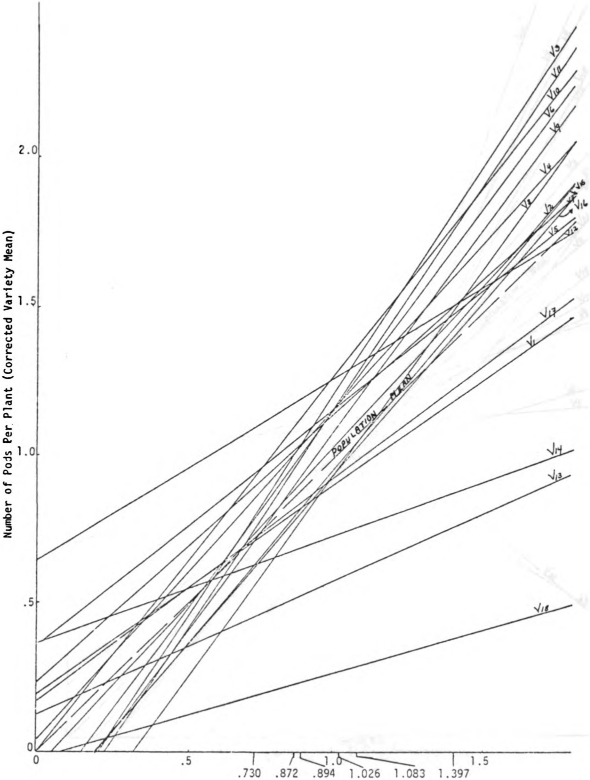


Figure 6. Regression lines showing the response (X) of 18 varieties to six different cultural environments.

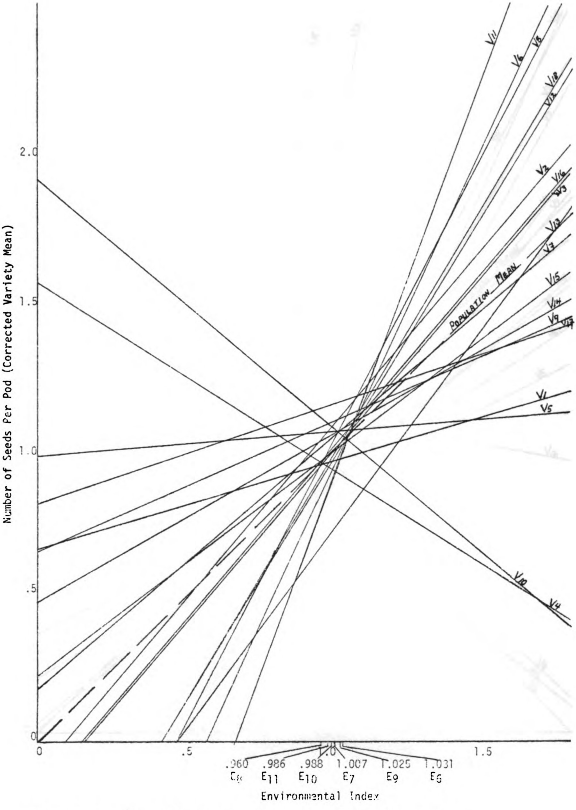


Figure 7. Regression lines showing the response (Y) of 18 varieties to six different cultural environments.

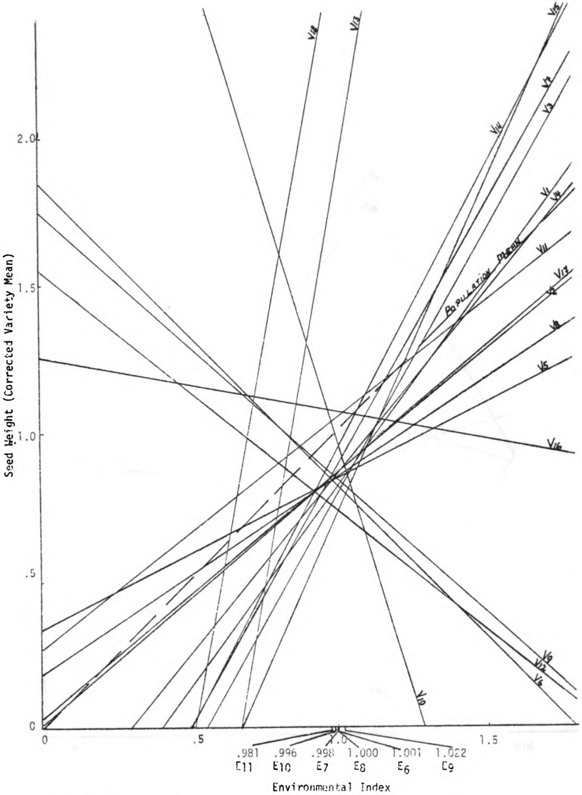


Figure 8. Regression lines showing the response (Z) of 18 varieties to six different cultural environments.

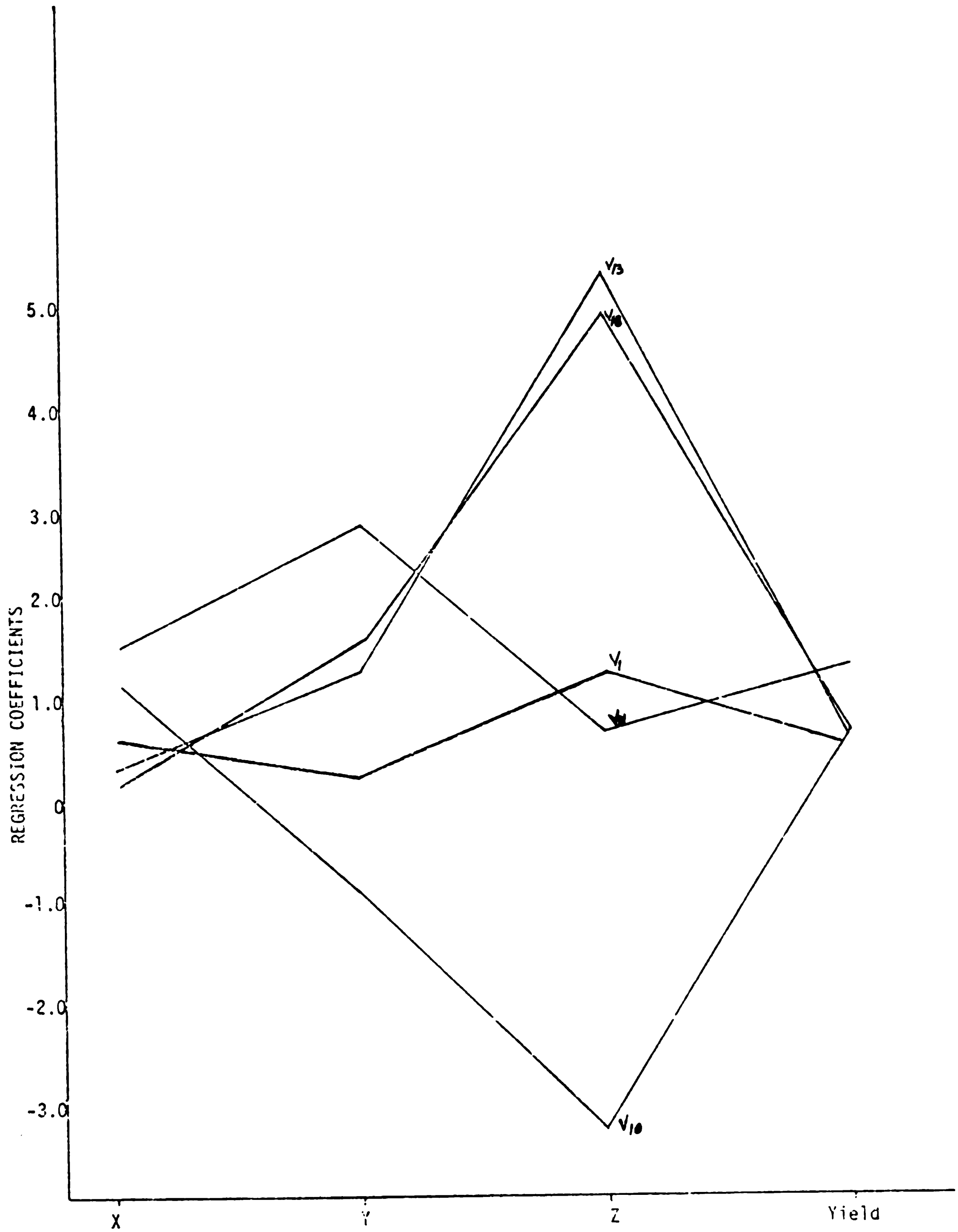


Figure 9. Fluctuation around the mean of the regression coefficients, for five varieties, calculated for yield components.

other upon these varieties which appear to behave with great positive or great negative slopes.

Multiple Regression Equation for Each Environment

As a guide toward developing an ideotype for associated culture of beans and maize, a multiple regression analysis was carried out for each cultural system with yield as the response variable and the yield components as independent variables (Table 10) in the first case and the individual yield components (X, Y, Z) as response variables and plant morphological traits as independent variables in the second case. The alpha level used in the stepwise regression was .10.

Location appeared to affect the relation between yield and yield components. At Jalpatagua, the yield components X and Z were in the equations to determine yield in all cultural environments, but Y appeared only in cultural environment 6. At Popayan, only X appeared in the equations for environments 9 and 11. Environment 10 did not have any yield component in the equation to determine yield. In the combined-environments analysis, all yield components appeared in the equation. Number of pods (X) contributed most to yield, followed by Z. All were positive.

By definition, yield is equal to the product of pod number per unit area (X), number of seeds per pod (Y) and weight of a single seed (Z); symbolically, Yield = $X \cdot Y \cdot Z$. Clearly it would be of interest to know what traits influence the yield components and their relative importance.

Figures 10 to 12 show the relative importance of each trait influencing yield components in environments 6 to 11.

Table 10. Equations found by multiple regression analysis (stepwise procedure), to explain yield as a function of X, Y and Z in environments 6 to 11 and environment combinations with values of the corresponding standard partial regression coefficients and the determination coefficient (R^2). Alpha level .10.

Dependent component of yield	Single Environment						Environments Combination		
	6	7	8	9	10	11	6-9	7-10	8-11
X	.5896	.8830	.8743	.5602	---	.5583	.7121	.8038	.7690
Y	.4266	---	---	---	---	---	.3918	.3078	.3288
Z	.7614	.3590	.3871	---	---	---	.5286	.6174	.4190
R^2	.5032	.6757	.5594	.3139	---	.6656	.6656	.5543	.4701

Monoculture, environments 6 and 9, associated culture short maize, environments 7 and 10, and associated culture tall maize, environments 8 and 11 were compared in the interpretation of these results.

Monoculture, Environments 6 and 9

A leaf factor, either LA or LDW and NR suggests leaf area and number of racemes as the most important integrating factor affecting X in monoculture.

A time factor, either DFFL or DM, higher PLH and NR were important factors affecting Y in monoculture.

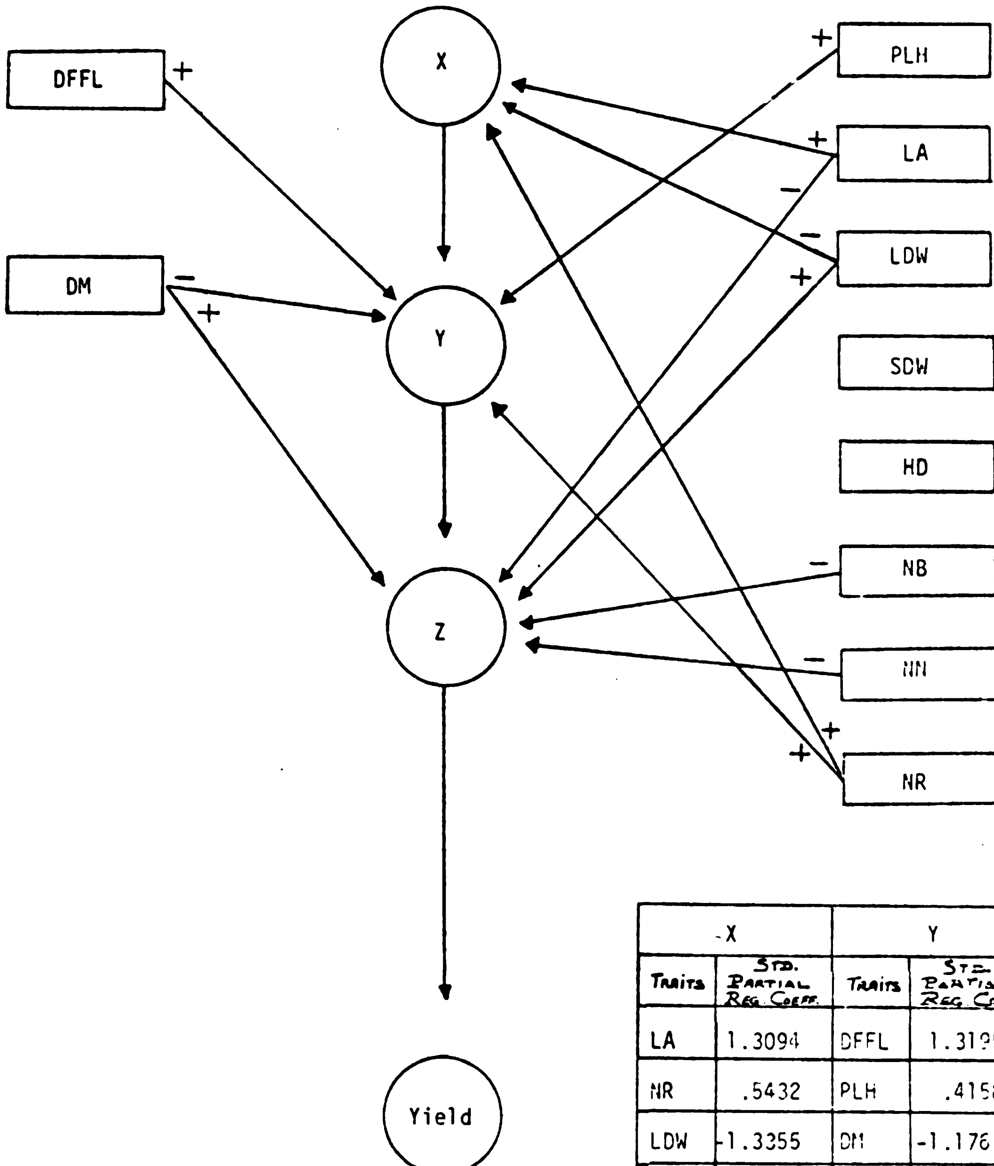
Leaf area (LA), NB and NN affected Z negatively, but LDW and DM affected Z positively in monoculture (Figure 10).

Associated Culture, Short Maize, Environments 7 and 10

Number of branches (NB) affected X positively, but was negative for Z. Number of racemes (NR) had a positive effect on both X and Y. Plant height (PLH) and HD were positive for Y, but SDW and DM affected Y negatively. Leaf area (LA) was negative for Z and LDW and DM were positive (Figure 11).

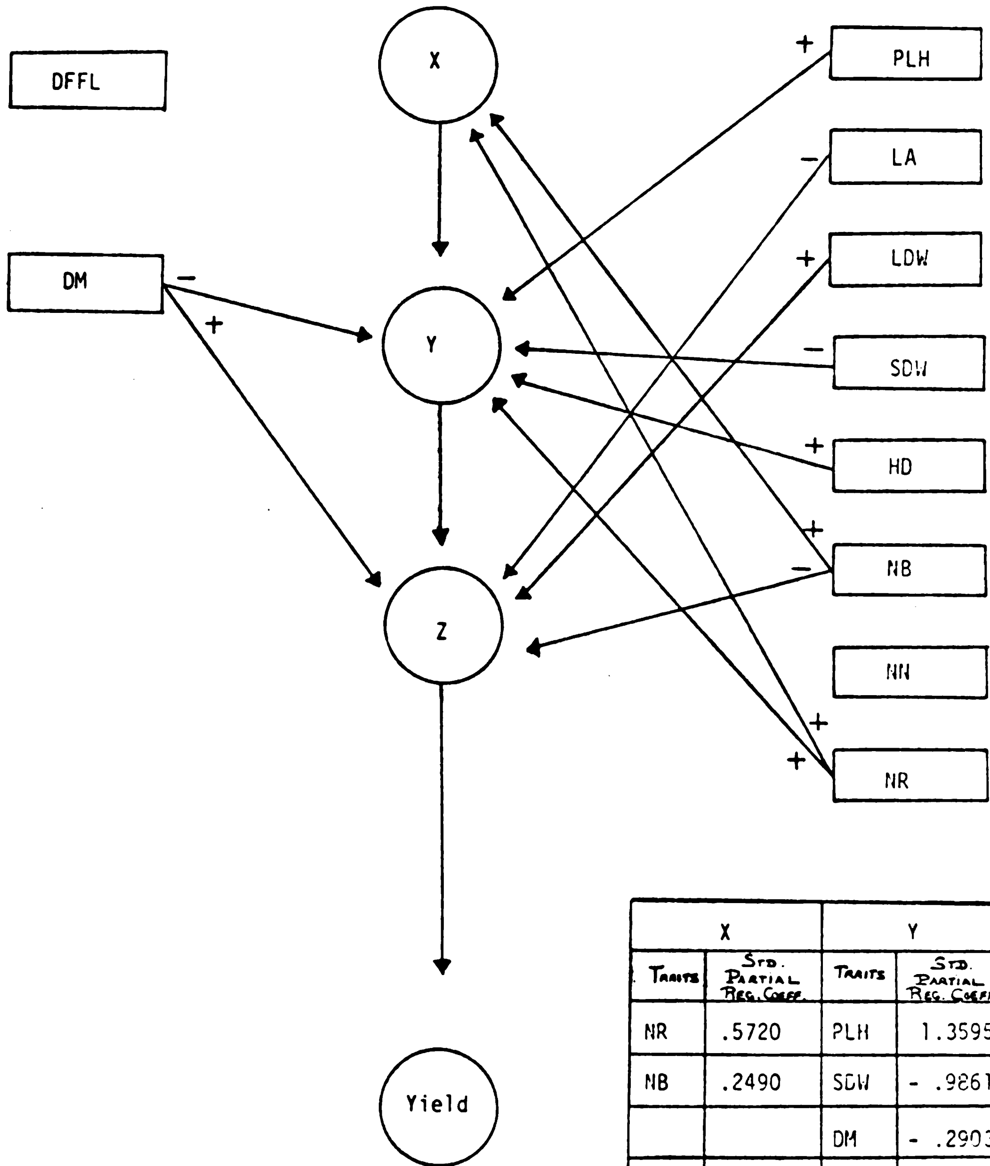
Associated Culture, Tall Maize, Environments 8 and 11

Days to maturity (DM), LA, HD and NR affected X positively; also LA affected Y positively but Z negatively. Number of racemes (NR) also affected Z, but negatively. Days to first flower (DFFL), NB and LDW affected X negatively; LDW affected Y negatively, but Z, positively. Plant height (PLH) affected Z positively (Figure 12).



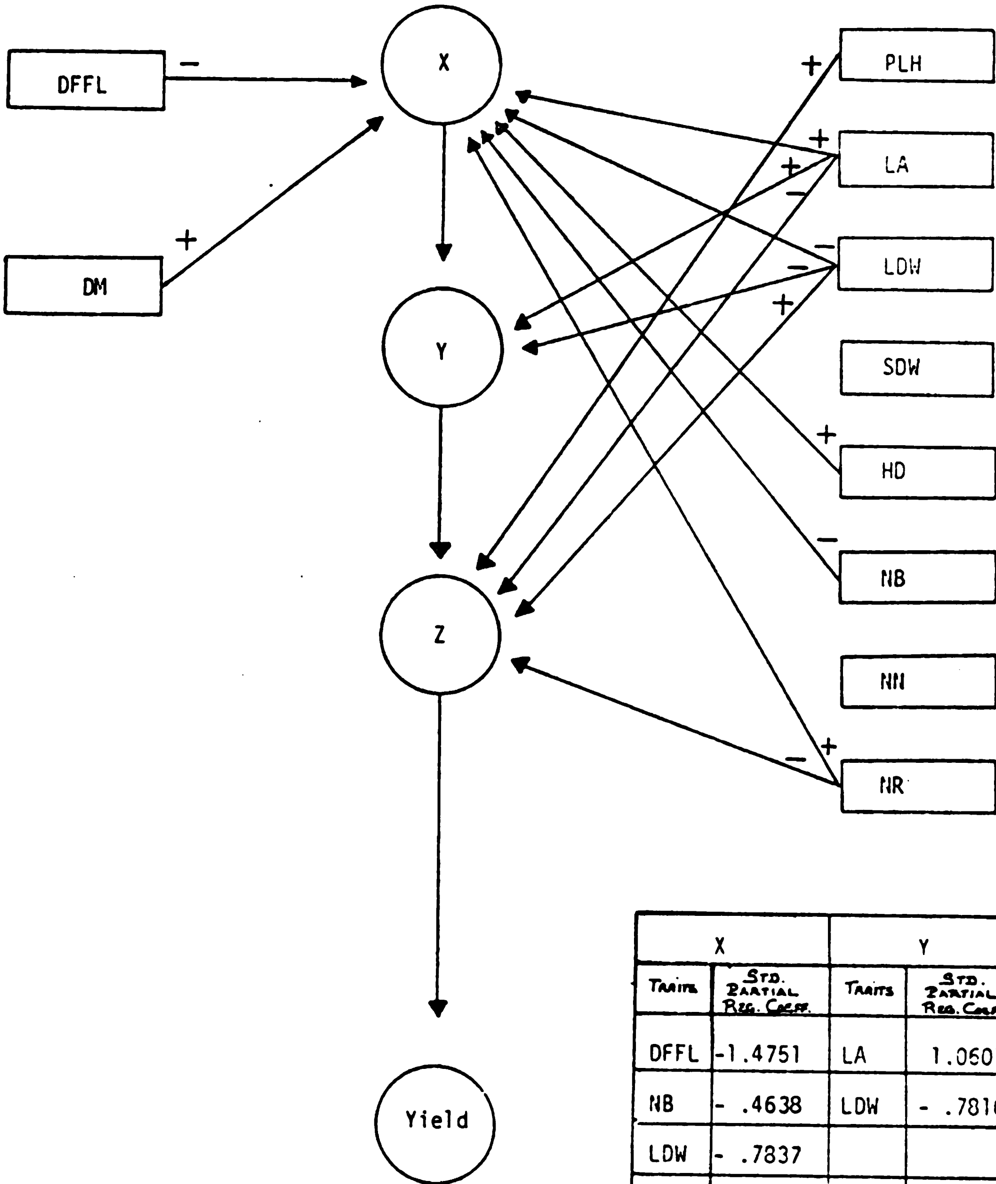
X		Y		Z	
Traits	Std. Partial Reg. Coeff.	Traits	Std. Partial Reg. Coeff.	Traits	Std. Partial Reg. Coeff.
LA	1.3094	DFFL	1.3195	LA	-1.0710
NR	.5432	PLH	.4158	NB	- .6038
LDW	-1.3355	DM	-1.1767	NN	- .3436
		NR	.5360	LDW	1.4821
				DM	.2995
R	.7314		.6977		.8327
R^2	.5349		.4868		.6934

Figure 10. Path diagram of effects of traits on components of yield for environments 6 and 9. Plus and minus signs next to each path indicate whether the effect of an increase of the variable is to increase or decrease the component. The Table included shows the values of the corresponding standard partial regression coefficients and the determination coefficients (R2).



	X		Y		Z	
	Traits	Std. Partial Reg. Coeff.	Traits	Std. Partial Reg. Coeff.	Traits	Std. Partial Reg. Coeff.
	NR	.5720	PLH	1.3595	LA	- .8842
	NB	.2490	SDW	- .9861	NB	- .7145
			DM	- .2903	DM	.2725
			NR	.3672	LDW	1.0202
			HD	.4874		
R	.7001		.6066		.8245	
R^2	.4901		.3680		.6798	

Figure 11. Path diagram of effects of traits on components of yield for environments 7 and 10. Plus and minus signs next to each path indicate whether the effect of an increase of the variable is to increase or decrease the component. The Table included shows the values of the corresponding standard partial regression coefficients and the determination coefficients (R2).



X		Y		Z	
Traits	Std. Partial Reg. Coeff.	Traits	Std. Partial Reg. Coeff.	Traits	Std. Partial Reg. Coeff.
DFFL	-1.4751	LA	1.0601	LDW	.6675
NB	- .4638	LDW	- .7810	LA	-1.2332
LDW	- .7837			PLH	.9189
NR	.7665			NR	- .3797
HD	.5791				
DM	1.6147				
LA	.4966				
R	.8374		.5570		.7515
R^2	.7012		.3103		.5647

Figure 12. Path diagram of effects of traits on components of yield for environments 8 and 11. Plus and minus signs next to each path indicate whether the effect of an increase of the variable is to increase or decrease the component. The Table included shows the values of the corresponding standard partial regression coefficients and the determination coefficients (R2).

Figure 13. Association culture of beans with tall corn, two months after planting at Palmira.

Figure 14. Association culture of beans with short corn, two months after planting at Palmira.

Figure 15. Association culture of beans with short corn (foreground) and tall corn (background), two months after planting at Palmira.

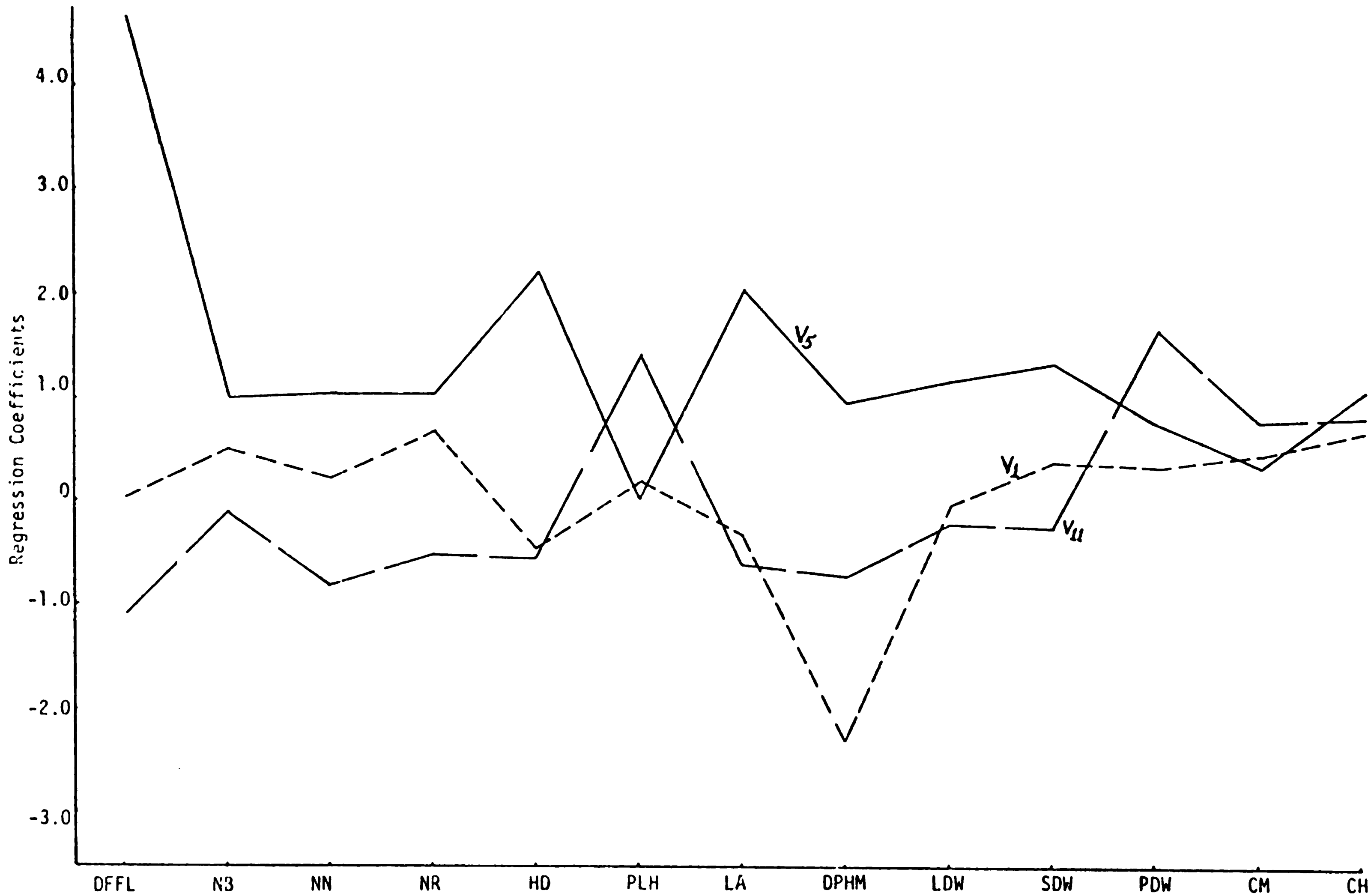


Figure 16. Fluctuation around the mean of the regression coefficients for three varieties, calculated for 13 traits.

DISCUSSION

There proved to be no significant differences between the cultural environments at Jalpatagua, possibly due to an early attack by *Spodoptera frugiperda* on the maize plants. Table 11 (see Appendix), shows varietal and environmental means for the 17 traits measured at Jalpatagua. The mean for each trait in environment 1 was below the mean of other environments in almost all the traits. It suggests that intraspecific competition was stronger than interspecific competition at this location. Environments 3 and 5 appear to be the best environments for the expression of all the traits studied at Jalpatagua since the means for all traits except Z, in these two environments, were above the other environmental means at this location.

At Popayan, there was some deficiency of magnesium and high concentrations of manganese due to the soil acidity (pH = 4.8) which affected bean and maize development. This situation explains why the different cultural systems were not as different as in Palmira where there was not any soil fertility problem.

All varieties had longer growing periods at Popayan than at Palmira. This was probably due to a temperature effect since both locations have similar day length. Thus, traits DFFL, DPHM and DM had higher mean values at Popayan. All the other traits, except HB, had higher mean values at Palmira. Longer vegetative periods would allow, perhaps promote, higher NB.

Bean monoculture environments 6 and 9, with no interspecific competition, appeared to be the best for the expression of most of the traits considered at Popayan and Palmira. For the trait PLH, environments 6 and 9 were not the best ones and this is due to the light competition that occurs in the association of beans and maize.

Environments 7 and 8 can be considered as the poorest for the expression of the bean traits measured at Popayan. Since environment 8 is the association of beans with tall maize, it exerted more competition over the bean plant than environment 7 which is the association of beans and short maize. The results showed that the mean in almost all of the traits in environment 8 were lower than in environment 7 with the exception of DFFL and DM (Table 12, Appendix).

Environment 11, which is the association of beans and tall maize, was the most competitive environment for all genotypes at Palmira. The maize hybrid H-210 used for this environment had a rapid growth rate in the first two months after planting which subjected the bean plants to too much competition at the early stages of development. Environment 10 had a less competitive effect than environment 11. This was due mainly to short plant type and slow growth rate of the maize hybrid H-207 used for this environment. The differences between short and tall corn are shown in Figures 13, 14 and 15.

Mean yields, regressions and environmental indices were dependent on the environments chosen and the varieties included. Therefore, to obtain a good estimate of the yielding potential of an environment, a large group of varieties should be included. To estimate the degress of stability of a set of varieties, the environments should represent the range of sites and/or cultural conditions in which the varieties are to be grown.

In the present study, the major differences for yield were due to cultural environment effects (Tables 6 and 7) at Popayan and Palmira. The contribution to yield differences of varieties as compared to environments was relatively high at Jalpatagua (mean square of environments versus mean square of varieties) but small at Popayan and Palmira. This can also be seen from the magnitude of environmental indices, Table 8, versus differences between varietal means, Table 9.

For a large number of traits, the major differences were due to varietal effects (mean square, Table 6). These differences were not constant over location. Varietal effects for NR were higher than environmental effects at Popayan but smaller at Palmira. This situation occurred for other traits such as NB, HD and LDW. This occurred because varieties at Popayan appeared to have differential response to soil acidity, and there were some traits such as NB, HD, PLH and DM that were more affected than other traits.

The relations found between yield components were the same that Silvera (loc. cit.) reported in his study. Adams (1967) reported negative correlation between X, Y and Z. These relations make it more difficult for plant breeders to create an ideal plant type.

The interaction effect between varieties and environments from the combined analysis of variance could not be partitioned into regression because the varieties means used in the regression analysis were in percentage of the location mean.

Varieties 1 and 13, Type I, had in common that their average yielding abilities were much lower and thay also responded less to more favorable cultural environments, but Variety 17, Type IV, responded positively to cultural environments.

Growth habit was the major variety characteristic that determined varietal performance in almost all cultural environments. Varieties of Type I were relatively stable to cultural environmental changes. Type II varieties appeared to be adapted to cultural environmental changes and varieties of Type III and IV have differential responses to cultural environment changes.

In terms of adaptation, Variety 5 appeared to be the most adapted because it was the variety with the highest number of traits with b-values nonsignificantly different from 1.0. Out of 17 traits measured, 10 were nonsignificant. This variety was almost equally well adapted to monoculture and associated culture. Variety 1 was the most stable variety with half of its traits showing b-values close to 0. This variety performed in a similar way under monoculture or associated culture. Variety 11 was the least adapted to cultural environment improvement with nine traits having negative b-values and only three traits with b-values nonsignificantly different from 1.0. This variety was adapted to associated culture. Variety 8, with a high number of traits with b-values greater and significantly different from 1.0, was unstable and adapted to monoculture (Figure 16).

Some varieties that were high yielding in monoculture were also high yielding in association. For instance, Variety 5 was high yielding in both monoculture and association at Popayan and Palmira. Variety 12 was high yielding in monoculture and association at Popayan and Variety 17 was high yielding in monoculture and association at Palmira. In general, varieties that were high yielding in monoculture tended to be low yielding in association (Varieties 4, 6, 8, 11 and 15 show this pattern in Figure 5), and varieties that were low yielding in monoculture tended to be high yielding in association (see Varieties 1, 9, 13, 14 and 18 in

Figure 5). This suggests that a variety can not be selected for yield in the monoculture system that would also be successful in the association system.

The goal in our use of multiple regression analysis was to identify those plant morphological traits that have independent positive or negative contributions to yield.

All of the factors express their effects upon yield through one or more of the primary components of yield (X, Y and Z) and these effects have been diagrammed in Figures 10 to 13. The value of the figures is to show the basic paths of influence upon yield, quantified by coefficients of the major plant constituents. If it were desirable for purposes of selection, these constituents could be rather accurately measured and an index of selection calculated. They do not, of course, completely determine yield, and sometimes, as environment 7 shows, poorly determine yield. The residual yield variance ($1 - R^2$) must be apportioned, some to structural-architectural factors and some to physiological processes, therefore, the yield system is not simply a sum of various traits in sub-systems but an interacting and richly compensating one.

Reference will be made to the case of cultivar #5 in order to illustrate the integration of adaptational and yield component traits.

Cultivar #5, widely adapted according to the Finlay-Wilkinson criteria, shows good adaptation for those traits (DFFL, NR, LA) important to the determination of X and Y in a monoculture system. The time factor (DFFL) appears not to be important in the association with short maize but it had a negative effect upon X in association with tall maize. Number of racemes and leaf area were important for all three cultural systems for the determination of X and Y. This suggests

NR and LA as the most important positive integrating factors affecting X and Y in all cultural systems.

Number of branches inhibited Z in monoculture and in association with tall maize. The same effect occurred with Y in association with short maize. This trait appeared to diminish yield. Number of nodes was an inhibiting trait for Z in monoculture. Variety 5 was adapted to environmental changes for NB and NN.

Plant height promoted Y in monoculture and association. The same effect occurred for Z in association with tall maize. This suggested plant height as an important factor, increasing yield in monoculture and in association. Variety 5 was highly phenotypically stable for this trait.

Leaf dry weight appeared to be a promoting factor for Z in all environments, but a diminishing factor for X and Y. Cultivar #5 showed high adaptation for this trait.

Days to maturity had contrasting values for Y and Z. When its effect promoted Z, a negative effect occurred in Y. Cultivar #5 was phenotypically stable for this trait.

SUMMARY AND CONCLUSIONS

The qualitative effects of 17 traits upon certain parameters of adaptation were determined in a bean population grown in six different cultural environments at two locations in Colombia, South America. The cultural environments were determined by location, crop system, maize type and planting pattern. The five cultural environments established in Guatemala were not considered in the final analysis of adaptation.

The bean population consisted of 18 varieties selected for different combinations of growth habit, flowering time, leaf area and yield components, namely the number of pods per plant (S), number of seed per pod (Y) and seed weight (Z). Maize selection was based on plant height. In each location, an adapted short or an adapted tall maize variety was used.

Parameters of adaptation were determined for each variety for each of the 17 traits. These parameters were slightly different from those of Finlay and Wilkinson because our purpose was to remove the geographic location effect and consider only the environmental effect produced by the different cultural systems. The variety mean and environment mean were adjusted by division by the location mean.

It is considered that varieties are best adapted when the regression of variety scores upon the respective environmental indexes approach unity, and they have high mean values for the characters under consideration.

In terms of the two adaptation measures, variation among varieties was greatest for Y, Z, DFFL, DM, DPHM, HD, PLH, LA, somewhat less for NB, NN, NR, LDW, SDW, CH and least for X, PDW and Yield. These three groups appear to progress from the least complex traits, in a developmental and a genetic sense, to the most complex, suggesting adaptational stability increased with an increase in the complexity of the trait.

Growth habit was the major varietal characteristic that determined varietal performance in almost all cultural environments. Varieties of Type I were stable ($b \to 0$) for cultural environmental changes. Type II varieties appear to be best adapted to cultural environmental changes ($b \to 1$) and varieties of Type III and IV have differential responses to cultural environment changes ($b \gtrless 1$).

Bean monoculture environments 6 and 9 were the best for high mean expression of most of the traits measured. For the expression of PLH and CH, cultural environment 11 was the best and for DPHM, cultural environment 7 was the best.

Some varieties that were comparatively high yielding in monoculture were also high yielding in the associations, but in general, varieties high yielding in monoculture tended to be low yielding in associations and varieties low yielding in monoculture, tended to be high yielding in associations. This suggests that a variety cannot be selected for yield in the monoculture system to be grown in the association system. It should be noted, however, that only in one case (Variety 11) was the regression value significantly different from unity.

From results of the multiple regression analysis, it is concluded that NR, PLH, HD and LDW were important to the determination of yield through the determination of yield components for the association of bean and short maize, but NB and DM had contrasting values for yield components. Stem dry weight and LA had negative effects upon yield. The traits HD, DM and PLH were important to the determination of yield components in the association of bean and tall maize, but LDW, NR and LA had contrasting values for yield components. Days to first flower and NB had negative effects upon yield. This suggests that plant breeders will have to make compromises in their decisions concerning the best set of traits in any given cultural environment.

Variety 5, with good general adaptability and capable of producing very high yields in all the cultural environments considered in the present study, also showed regression values near unity for most of the morphological traits measured. In extrapolation from this example, it may be postulated that for a variety to be widely adapted to mixed cultural environments it should show good adaptation for most of the morphological traits important in yield determination.

Variety 1 was the least well adapted variety with respect to yield. Interestingly, none of the morphological traits showed regression slopes close to unity, all being below one and most, near zero. This case was the converse of the situation with Variety 5, but was consistent with the postulate arrived at on the evidence of Variety 5 and tends to reinforce that postulate.

LITERATURE CITED

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

Adams, M. W. 1973. Plant architecture and physiological efficiency in the field bean. In Potentials of Field Beans and Other Food Legumes in Latin America. CIAT, Cali, Colombia. 266-278 pp.

Agboola, K. A., and A. A. Fayemi. 1971. Preliminary trials on the intercropping of maize with different tropical legumes in Western Nigeria. J. Agr. Sci. Camb. 77:219-225.

Allard, R. W., and A. D. Bradshaw. 1964. Implications of genotype-environmental interactions in applied plant breeding. Crop Sci. 4:503-508.

Alvim, R., and P. Alvim. 1969. Efeito da densidade de plantio no aprovestamento de energia luminosa pelo milho (Zea mays) e pelo feijao (Phaseolus vulgaris), em cultura exclusivas e consorciadas. Turrialba 19:389-393.

Basan, R., A. M. Pinchinat, B. Paez, N. Mateo, J. Fargas, and W. Forsythe. 1975. Investigacion sobre sistemas de produccion agricola para el pequeno agricultor del tropico. Turrialba 25:283-293.

Bliss, F. A. 1971. Inheritance of growth habit and time of flowering in beans, Phaseolus vulgaris L.. Amer. Soc. Hort. Sci. 96: 715-717.

Bradshaw, A. D. 1965. Evolutionary significance of phenotypic plasticity in plants. Adv. in Gen. 13:115-155.

Burke, D. W., and C. F. Nelson. 1965. Effects of rows and plant spacing on yields of dry beans in Fusarium-infested and non-infested fields. Wash. Agr. Exp. Sta. Bull. No. 664.

Camacho, L. H. 1968. Estabilidad y adaptabilidad de lineas homocigotas de frijol Phaseolus vulgaris L. y su implicacion en la seleccion por rendimiento. Revista Instituto Colombiano Agropecuario. 3:165-178.

CIAT, Cali, Colombia. 1975. Annual report. 60-62 pp.

CIMMYT, Batan, Mexico. 1972. Annual report. 139-143 pp.

Clausen, J., D. D. Keck, and W. M. Hiesey. 1948. Experimental studies on the nature of species. III. Environmental responses of climatic races of Achillea. Carnegie Inst. Wash. Pub. No. 581.

Coyne, D. P. 1966. The genetics of photoperiodism and the effect of temperature on the photoperiodic response for time of flowering in Phaseolus vulgaris L.. Proc. Amer. Soc. Hort. Sci. 89: 350-360.

Coyne, D. P. 1970. Genetic control of a photoperiodic temperature response for time of flowering in beans (Phaseolus vulgaris L.). Crop Sci. 10:246-248.

Coyne, D. P., and M. L. Schuster. 1974. Inheritance and linkage relation of reaction to Xanthomonas phaseoli (E. F. Smith) Dowson (common blight), stage of plant development and plant habit in Phaseolus vulgaris L.. Euphytica 23:195-205.

Davis, D. W. 1963. Quantitative inheritance of growth habit in the bush bean, Phaseolus vulgaris L. Diss. Abs. 24:3061-3062.

Davis, D. W., and A. F. Frazier. 1966. Inheritance of some growth habit components in certain types of bush lines in Phaseolus vulgaris L.. Amer. Soc. Hort. Sci. 88:384-392.

Denis, J. C. 1971. Factor analysis of plant-type variables related to yield of dry beans (Phaseolus vulgaris L.). Ph.D. thesis, Mich. State Univ.

Donald, C. M. 1968. The breeding of crop ideotypes. Euphytica 17:385-403.

Draper, N. R., and H. Smith. 1966. Applied regression analysis. John Wiley & Sons, Inc., New York. 407 p.

Duarte, R. 1961. Component interaction in relation to mean expression of complex traits in a field bean cross. M.S. thesis, Mich. State Univ.

Eberhart, S. A., and W. A. Russell. 1966. Stability parameters for comparing varieties. Crop Sci. 6:36-40.

Emerson, R. A. 1916. Genetic study of plant height in Phaseolus vulgaris. Nebr. Agr. Exp. Sta. Res. Bull. No. 7.

Enyi, B. A. C. 1973. Effects of intercropping maize or sorghum with cowpeas, pigeon peas or bean. Exp. Agr. 9:83-90.

Francis, C. A., C. A. Flor, and S. R. Temple. 1975. Adapting varieties for intercropped system in the tropics. Presented in American Society of Agronomy Annual Meeting, 1975. Accepted for ASA Special Publication Series. 36 p.

Francis, C. A., C. A. Flor, and M. Prager. 1976. Potentials of bean-maize associations in the tropics. Manuscript submitted to Fitotecnia Latinoamericana. 19 p.

Finlay, K. W., and G. N. Wilkinson. 1963. The analysis of adaptation in a plant breeding program. Aust. J. Agr. Res. 14:742-754.

Gutierrez, V., M. Infante, and A. M. Pinchinat. 1975. Situacion del cultivo de frijol en America Latina. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. Serie ES-19. 33 p.

Harper, J. L. 1961. Approaches to the study of plant competition. Symp. Soc. Exptl. Bio. 15:1-39.

Harper, J. L., and D. Gajic. 1961. Experimental studies of the mortality and plasticity of a weed. Weed Res. 1:91-104.

Hart, R. D. 1975a. A bean, corn and manioc polyculture cropping system. I. The effect of interspecific competition on crop yield. Turrialba 25:294-301.

Hart, R. D. 1975b. A bean, corn and manioc polyculture cropping system. II. A comparison between the yield and economic return from monoculture and polyculture cropping systems. Turrialba 25:377-384.

Hess, W. M. 1960. Inheritance of growth habit in bush beans, Phaseolus vulgaris. M.S. thesis, Oregon State College.

Jennings, P. R. 1964. Plant type as a rice breeding objective. Crop Sci. 4:13-15.

Johnson, H. W., F. Robinson, and R. E. Comstock. 1955. Estimates of genetic and environment variability in soybeans. Agron. J. 47:314-318.

Krutman, S. 1968. Cultura consorciada cana x feijoeiro. Primeros resultados. Pesq. Agropec. Brasileira 3:127-134.

Kurtz, T., S. W. Melsted, and R. H. Bray. 1952. The importance of nitrogen and water in reducing competition between intercrops and corn. Agron. J. 44:13-17.

Leakey, C. L. A. 1962. The effect of plant population and fertility level on yield and its components in two determinate cultivars of Phaseolus vulgaris L.. Agr. Sci. 79:259-367.

Lepiz, I. R. 1971. Asociacion de cultivor maiz-frijol. Agriculture Tecnica en Mexico 3:98-101.

Lugo-Lopez, M. A., B. G. Capo, F. Arostegui, and A. Riollano. 1953. Intercropping sugarcane with food crops. J. Agr. Univ. Puerto Rico. 37:171-182.

Mancini, M.S., and M. A. Castillo. 1960. Observaciones sobre ensayos preliminares en el cultivo asociado de frijol de enredadera y maiz. Agricultura Tropical (Colombia). 16:161-166.

Medina, J. C. 1972. O feijao no Brasil. In Simpocio Brasileiro de Feijao, Campinas, 1971. Univ. Federal de Vicosa. 3-14 pp.

Miranda, C. A. 1966. Inheritance of growth habit in Phaseolus vulgaris. Agrociencia (Mexico). 191:77-83.

Mock, J. J., and R. B. Pearce. 1975. An ideotype of maize. Euphytica 24:613-623.

Morishima, H., H. I. Oka, and T. T. Chang. 1967. Analysis of genetic variations in plant type of rice. I. Estimation of indices showing genetic plant types and their correlations with yielding capacity in a segregating population. Jap. J. Breeding 17: 73-84.

Nicol, H. 1936. The utilization of atmospheric nitrogen by mixed crops. Int. Rev. of Agr. 27:201-206.

Nowotny, A. 1937. An investigation of nitrogen uptake in mixed crops not receiving nitrogenous manure. J. Agr. Sci. 27:503-510.

Osiru, D. S. O., and R. W. Willey. 1972. Studies on mixtures of dwarf sorghum and beans (Phaseolus vulgaris) with particular reference to plant population. J. Agr. Sci. Camb. 79:531-540.

Plaisted, R. L., and L. C. Peterson. 1959. A technique for evaluating the ability of selections to yield consistently in different locations or seasons. Amer. Potato J. 36:381-385.

Plaisted, R. L. 1960. A shorter method for evaluating the ability of selections to yield consistently over locations. Amer. Potato J. 37:166-172.

Rowe, P. R., and R. H. Andrew. 1964. Phenotypic stability for a systematic series of corn genotypes. Crop Sci. 4:563-567.

Scott, G. E. 1967. Selecting for stability of yield in maize. Crop Sci. 7:549-551.

Silvera, G. A. C. 1974. Incorporation of germplasm of the seafarer navy bean into several Central and South American bean cultivars, in relation to breeding for improvement in adaptation. Ph.D. thesis, Mich. State Univ. 98 p.

Singh, R. D., and P. Chand. 1969. Intercropping of maize with forage legumes. Indiana J. Agron. 14:67-70.

Sixto, D. 1975. Produccion de maiz y frijol comun asociados segun habito de crecimiento y poblacion de plantas. M.S. thesis, Turrialba, Costa Rica. 41 p.

Stebbins, G. L. 1960. Variation and evolution in plants. Columbia Univ. Press, New York.

Tanaka, A. 1974. Studies on physiology of _Phaseolus vulgaris_. Annual Report 1974, Laboratory of Plant Nutrition. Faculty of Agr., Hokkaido Univ., Sapporo, Japan. 38 p.

Virtanen, A. I., S. Hausen, and T. Laine. 1937. Investigations on the root nodule bacteria of leguminous plants. J. Agr. Sci. 27:584-610.

Vogel, O. A., R. E. Allan, and C. J. Peterson. 1963. Plant and performance characteristics of semi-dwarf wheats producing most efficiently in eastern Washington. Agron. J. 55:397-398.

Walton, P. D. 1972. Factor analysis of yield in spring wheat (_Triticum aestivum_ L). Crop Sci. 12:731-733.

Willey, R. W., and D. S. A. Osiru. 1972. Studies on mixtures of maize and bean (_Phaseolus vulgaris_) with particular reference to plant population. J. Agr. Sci., Camb. 79:517-529.

Yates, F., and W. C. Cockran. 1938. The analysis of groups of experiments. J. Agr. Sci. 28:556-580.

APPENDIX

Table 11. Mean values of 17 traits measured for 11 varieties in five cultural environments at Jalpatagua.

Environment		Varieties										
No.	Mean	1	2	3	4	5	6	7	8	9	10	11
DFFL												
1	34.44	29.0	35.7	36.0	36.3	35.3	36.3	30.0	35.3	33.7	35.0	31.3
2	34.72	29.0	36.0	35.7	36.0	36.0	36.3	30.0	35.3	35.3	26.0	31.3
3	34.72	29.0	36.0	36.0	35.3	35.3	35.3	30.0	36.3	35.7	36.0	31.3
4	34.67	29.0	37.0	36.0	35.7	35.3	36.0	29.7	36.0	34.7	35.7	31.3
5	34.75	29.0	36.0	36.0	36.0	36.3	37.7	30.3	35.7	34.0	35.0	31.3
NB												
1	3.16	2.73	3.33	4.60	3.13	2.86	2.40	2.07	2.47	3.80	3.27	3.20
2	3.50	2.20	4.13	4.46	3.93	3.13	3.20	2.80	3.53	3.20	3.07	3.73
3	3.77	2.13	4.33	4.73	4.80	3.47	3.47	3.26	3.73	3.60	3.60	3.26
4	3.37	2.60	3.73	4.67	4.13	2.60	2.73	2.53	3.53	3.33	2.60	3.67
5	3.62	2.40	4.37	5.27	4.00	2.73	3.26	2.60	3.33	3.67	3.80	3.27
NN												
1	16.63	12.8	17.7	17.1	19.1	13.3	13.3	12.6	11.5	17.3	18.3	20.7
2	18.00	10.7	19.3	18.4	15.9	14.2	14.3	17.1	17.3	18.9	18.8	23.5
3	18.67	11.5	19.7	18.7	21.2	14.5	16.0	17.8	15.3	20.3	19.7	21.6
4	16.86	11.9	16.8	18.1	17.9	13.4	14.8	15.1	14.6	16.5	15.2	21.7
5	18.66	13.9	18.7	19.9	18.3	14.5	18.1	16.7	15.8	20.1	20.7	21.7

Table 11 (cont'd.)

NR												
1	9.81	10.3	9.5	9.8	11.5	6.8	8.7	9.7	6.1	11.8	10.6	14.1
2	11.35	9.3	11.3	11.2	9.6	7.8	9.9	13.2	9.9	12.8	11.8	17.8
3	11.73	9.5	12.9	11.1	13.9	7.9	9.1	13.2	8.9	14.1	12.3	15.9
4	10.52	11.0	10.2	12.6	11.7	6.4	9.3	11.2	8.1	9.6	10.2	15.3
5	10.97	11.1	9.5	12.5	10.5	8.5	10.7	12.9	8.1	11.3	12.6	13.6
HD												
1	.4983	.498	.505	.539	.525	.527	.506	.449	.475	.483	.530	.447
2	.5066	.466	.573	.575	.512	.494	.531	.473	.527	.488	.475	.458
3	.5384	.479	.590	.538	.629	.561	.539	.499	.565	.496	.528	.460
4	.5103	.498	.527	.567	.540	.534	.537	.446	.536	.478	.475	.467
5	.5459	.542	.598	.605	.575	.572	.593	.512	.549	.517	.537	.450
PLH												
1	59.66	39.1	86.2	46.8	60.2	33.1	38.9	52.4	33.8	77.5	78.9	63.3
2	70.76	39.8	92.9	57.9	53.3	38.6	50.3	74.3	60.7	84.4	93.0	70.6
3	68.31	40.4	90.5	51.3	70.1	39.3	49.5	68.3	50.3	70.5	90.5	67.4
4	62.97	40.3	83.4	47.8	54.0	27.5	48.3	58.9	45.1	81.1	80.5	72.0
5	66.79	44.5	94.7	55.2	61.2	35.7	47.4	73.4	47.6	71.7	90.2	67.1
LA												
1	16.16	13.03	19.68	17.73	19.58	14.21	12.21	10.31	13.16	16.59	17.54	12.42
2	18.65	10.86	22.60	22.10	16.29	13.84	15.29	21.12	22.94	15.97	18.15	15.82
3	17.49	12.38	22.98	19.32	23.04	14.86	15.68	17.36	18.90	17.62	13.23	16.23
4	15.27	11.24	16.39	14.43	16.55	13.15	14.71	14.69	17.33	13.27	13.58	12.44
5	18.59	16.02	21.45	21.51	17.28	15.67	21.04	16.27	16.87	17.47	18.06	13.40

Table 11 (cont'd.)

DPHM

1	65.78	59.0	68.3	68.7	70.7	67.0	69.3	60.0	67.7	64.3	66.3	62.3
2	65.70	59.0	67.0	68.0	69.3	70.7	69.7	60.0	67.0	64.3	65.7	62.0
3	65.91	59.0	68.3	69.3	69.7	69.3	69.7	60.0	67.7	64.0	65.7	62.3
4	65.77	59.0	68.3	68.3	68.3	68.3	70.0	60.0	68.3	64.0	66.7	62.3
5	67.64	60.7	70.3	70.3	71.3	71.3	70.7	61.7	70.3	65.7	68.0	63.7

LDW

1	3.36	2.00	3.58	4.23	3.47	3.07	2.79	2.41	3.37	3.60	3.16	2.21
2	3.45	2.04	4.90	3.84	2.47	3.79	3.40	2.41	4.25	2.81	3.38	1.72
3	3.94	2.72	4.36	4.44	3.93	3.79	3.29	3.84	3.57	3.80	3.34	3.01
4	3.14	1.90	3.08	3.23	2.83	3.09	3.68	2.66	3.62	3.01	3.41	2.10
5	4.12	2.29	4.81	5.10	4.66	4.23	3.77	3.53	4.02	3.50	3.20	3.77

SDW

1	3.79	2.42	3.91	3.39	4.36	3.40	3.39	2.12	4.10	3.80	4.11	2.93
2	3.93	2.14	5.15	4.70	3.32	3.64	3.95	1.95	4.37	3.36	4.30	2.79
3	4.55	2.85	4.67	4.74	5.61	4.49	3.91	3.03	4.57	4.23	4.02	3.83
4	3.70	2.44	3.53	3.23	4.61	3.14	4.09	2.30	4.12	3.60	4.20	2.86
5	4.83	2.61	5.00	6.13	7.44	4.04	5.13	3.34	4.44	3.19	4.33	4.35

PDW

1	7.97	9.93	10.83	6.45	8.73	7.67	6.30	7.53	7.20	7.88	5.04	10.12
2	7.79	7.79	11.75	8.65	7.59	5.95	5.21	7.64	8.33	9.08	5.38	8.37
3	8.60	9.02	10.65	6.47	10.37	6.55	6.01	10.17	8.81	10.37	6.55	9.67
4	7.33	8.82	7.43	5.83	8.40	5.41	6.31	8.85	8.45	8.15	4.98	8.01
5	8.74	8.93	7.36	9.07	9.63	8.87	6.06	11.03	9.83	7.39	8.03	9.90

Table 11 (cont'd.)

DM												
1	79.7	71.0	81.0	83.0	85.0	85.0	83.7	71.0	81.0	80.0	81.0	75.0
2	80.9	71.0	81.0	84.3	84.3	85.7	83.7	71.0	81.0	80.0	83.0	75.0
3	80.9	71.0	82.3	85.7	85.0	87.7	85.0	72.3	81.7	79.7	83.0	76.3
4	80.2	70.7	82.3	84.3	83.7	85.7	84.3	70.7	82.3	80.0	83.0	75.0
5	80.8	71.0	82.3	85.0	85.0	87.7	85.0	71.7	82.3	80.0	83.7	75.0
Yield												
1	1582	1548	1932	1619	1494	1848	1323	1624	1666	1401	1290	1659
2	1448	1097	1992	1556	1298	1564	1344	1509	1580	1341	1269	1380
3	1724	1632	2210	1597	1773	1848	1552	2059	1701	1615	1167	1809
4	1583	1662	1647	1469	1300	1610	1747	2106	1547	1441	1395	1492
5	1798	1665	2199	1930	1874	1783	1486	2124	1821	1471	1556	1874
X												
1	6.15	6.2	7.0	7.0	7.0	6.1	5.5	6.4	5.4	5.2	5.3	6.6
2	5.86	5.0	6.8	6.6	5.5	5.4	5.5	5.7	5.4	4.8	5.4	8.4
3	6.73	7.1	7.8	7.3	7.4	7.1	7.2	7.3	5.7	5.8	4.8	6.5
4	6.53	6.9	6.5	6.9	5.7	5.8	8.0	7.3	5.0	5.2	6.1	8.4
5	7.28	6.6	7.6	8.7	8.4	6.6	5.5	8.3	6.1	5.4	6.7	10.2
Y												
1	5.47	5.1	6.0	5.3	5.1	6.2	5.7	5.1	6.1	5.5	4.8	5.3
2	5.49	4.6	6.3	5.5	5.2	6.0	5.5	5.1	6.3	5.9	5.0	5.0
3	5.65	4.8	6.4	5.5	5.8	5.9	5.3	5.5	6.4	5.9	5.1	5.6
4	5.44	5.0	5.7	5.2	5.4	6.1	5.0	5.5	6.4	5.5	4.8	5.3
5	5.59	5.2	6.4	5.5	5.6	5.9	5.4	4.9	6.5	5.7	5.0	5.4

Table 11 (cont'd.)

Z												
1	20.40	21.9	20.6	19.5	18.7	21.8	18.8	23.0	22.2	21.4	22.3	14.2
2	20.51	21.2	20.7	19.3	19.8	21.9	19.7	23.4	21.0	21.4	22.7	14.5
3	19.84	21.4	20.1	17.6	18.3	20.0	18.3	23.0	21.2	22.3	21.4	14.7
4	20.37	21.6	20.3	18.4	18.8	20.8	19.5	23.7	21.7	22.6	22.0	14.7
5	20.07	21.7	20.3	18.3	18.0	20.7	18.8	23.6	20.9	22.3	20.9	15.3
CH												
1	43.18	41.4	42.9	46.4	45.0	46.4	43.1	39.5	50.0	38.3	44.1	38.7
2	43.82	37.6	45.2	46.0	45.1	45.3	48.9	37.9	46.2	44.1	44.8	36.0
3	46.37	44.5	44.5	45.7	51.3	52.0	51.1	42.0	49.3	41.3	46.4	40.4
4	44.53	39.7	46.1	45.3	47.5	41.5	48.5	43.5	45.7	40.5	46.3	41.9
5	46.37	41.5	49.0	51.6	52.5	44.3	51.1	42.1	50.3	42.3	44.9	39.8

Table 12. Mean values of 17 traits measured for 18 varieties in six cultural environments at two locations: Popayan and Palmira.

Environments No.	Environments Mean	Varieties 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
DFFL																			
6	52.37	41.7	58.0	52.3	52.0	52.7	51.3	42.0	51.3	58.3	50.0	49.3	46.0	41.3	56.0	52.0	51.7	60.0	66.7
7	51.91	42.0	58.0	52.7	51.3	50.0	52.0	41.3	51.7	59.0	50.0	49.7	46.0	41.0	58.0	51.7	53.0	59.3	67.7
8	51.97	41.7	56.7	52.7	51.3	52.3	52.0	42.0	50.7	58.0	50.0	49.7	46.0	41.3	57.7	53.3	52.3	59.7	68.0
9	42.28	32.0	43.7	41.0	41.7	42.7	41.7	32.3	42.7	50.0	41.0	44.0	34.3	35.3	41.3	42.0	44.7	50.3	60.0
10	42.42	32.0	43.3	42.0	42.7	44.0	42.3	33.0	43.0	44.0	41.3	42.3	34.7	35.0	43.0	42.0	45.3	53.3	60.0
11	42.14	31.7	42.3	41.3	42.0	42.3	42.7	32.7	42.3	46.3	42.0	42.0	33.7	34.7	42.3	42.3	43.7	54.3	60.0
NB																			
6	3.85	3.03	4.93	4.10	3.67	4.37	4.10	3.03	3.90	4.47	4.10	3.86	4.23	3.27	4.50	4.30	4.30	3.53	1.60
7	3.86	2.60	4.00	5.07	4.00	4.97	4.20	2.57	3.70	4.23	3.93	3.96	4.07	2.80	4.47	4.57	4.26	3.73	1.77
8	3.73	2.83	3.27	4.43	4.27	4.53	4.03	2.87	3.97	4.07	3.43	3.87	4.53	3.20	4.57	4.43	4.20	2.50	2.07
9	2.83	2.73	1.90	3.50	3.50	2.77	3.53	3.03	3.16	2.70	2.97	2.13	3.90	2.33	2.83	3.30	2.87	1.87	1.87
10	2.56	2.70	2.00	3.43	3.10	2.30	2.83	2.37	2.53	2.60	2.60	2.43	3.53	1.97	2.53	2.87	2.57	1.80	1.87
11	2.29	2.47	1.50	2.93	2.78	2.13	2.80	2.17	2.23	1.77	2.30	2.17	3.73	1.63	2.27	3.33	1.93	1.67	1.53
NN																			
6	20.19	15.2	24.1	19.7	16.1	18.5	18.6	15.5	17.4	26.0	20.9	20.5	26.9	11.8	18.5	21.2	28.0	21.6	22.9
7	19.91	15.0	19.3	25.0	17.5	22.4	19.8	14.5	17.3	19.2	23.9	19.7	27.4	9.0	17.8	19.8	25.7	19.5	25.5
8	19.57	15.1	14.4	17.5	19.0	20.9	17.5	16.2	18.4	25.0	17.9	20.0	30.6	9.6	18.5	20.4	30.6	15.4	25.2
9	27.03	15.8	24.3	27.1	25.4	21.8	24.3	22.4	23.6	40.8	24.8	24.1	31.6	14.1	18.3	25.5	33.1	34.3	55.2
10	22.96	15.3	17.9	21.3	23.6	16.0	21.2	17.2	19.1	32.5	19.0	30.1	25.2	12.1	14.2	16.6	29.0	32.5	50.4
11	22.07	14.2	21.3	21.6	20.3	16.5	20.5	17.6	16.2	28.2	19.8	26.8	26.0	10.9	14.0	22.3	22.7	30.7	47.7
NR																			
6	11.62	11.1	10.1	11.7	10.1	10.8	11.4	10.1	10.4	13.8	13.6	12.6	18.6	9.1	8.1	13.6	17.1	11.4	8.5
7	11.29	8.2	7.0	14.9	10.7	12.3	12.3	9.4	9.9	11.6	13.8	12.7	19.1	6.7	8.2	11.1	15.0	11.4	8.9
8	10.75	9.9	5.0	10.6	11.7	12.5	11.2	11.6	12.0	11.1	10.0	12.5	20.2	6.3	8.8	11.4	14.0	8.1	6.6
9	13.58	13.9	9.7	16.7	14.8	13.2	13.9	16.2	12.7	15.8	12.7	12.0	20.9	11.4	10.9	16.3	13.8	14.5	5.0
10	11.24	12.4	10.4	12.9	13.3	9.1	10.0	13.3	9.9	12.3	9.9	13.4	13.9	8.9	8.8	10.9	13.9	14.0	5.0
11	10.26	11.6	10.4	11.4	10.7	9.3	10.5	11.2	8.1	10.0	8.3	13.7	18.9	8.8	8.4	12.4	8.9	17.1	5.0

Table 12 (cont'd.)

HD																			
6	.5456	.521	.569	.570	.485	.532	.551	.479	.551	.509	.506	.486	.426	.613	.661	.570	.561	.685	.546
7	.5461	.511	.547	.675	.541	.621	.576	.463	.575	.500	.554	.474	.445	.556	.656	.594	.550	.521	.471
8	.5451	.600	.511	.565	.540	.616	.527	.522	.595	.497	.513	.488	.460	.568	.657	.579	.556	.487	531
9	.5459	.451	.536	.631	.607	.643	.603	.497	.626	.521	.517	.437	.379	.529	.633	.621	.514	.504	.578
10	.4987	.471	.498	.558	.580	.518	.529	.415	.525	.468	.448	.472	.356	.514	.571	.520	.487	.515	.531
11	.4855	.476	.482	.561	.510	.515	.528	.432	.514	.431	.450	.460	.336	.434	.554	.576	.473	.492	.535
PLH																			
6	58.95	37.6	56.1	37.4	39.9	32.2	44.1	49.3	46.3	89.5	58.9	67.6	60.0	39.1	50.8	40.4	68.6	67.0	176.2
7	59.80	33.1	42.3	44.4	47.1	50.0	48.5	54.5	51.9	78.2	60.9	66.2	59.2	36.4	47.3	44.0	63.4	79.4	169.7
8	57.28	42.0	35.1	43.0	46.4	47.6	39.7	56.4	52.4	81.1	48.3	62.9	55.3	33.7	51.0	40.9	60.5	75.3	163.9
9	119.50	60.8	132.1	98.9	102.5	84.2	102.0	88.5	102.6	180.2	105.8	125.8	82.3	46.0	99.6	80.1	119.3	202.1	338.3
10	118.62	71.0	125.1	88.1	105.9	99.8	100.7	75.9	99.8	157.3	100.1	138.4	78.9	46.1	102.4	92.1	124.1	198.9	330.6
11	126.99	77.3	158.5	100.6	109.9	94.9	102.9	96.6	97.3	172.9	110.7	144.5	81.5	52.0	107.0	105.6	124.0	217.2	342.5
LA																			
6	11.34	9.53	13.88	9.17	8.08	9.10	9.10	9.29	12.54	13.41	12.01	9.01	10.93	8.03	13.64	14.26	15.54	13.59	13.00
7	12.44	6.88	11.03	18.85	15.03	15.43	13.56	10.59	12.59	9.99	13.52	10.27	11.63	6.36	12.65	11.27	14.05	15.21	13.99
8	11.93	10.68	9.66	11.45	13.37	17.16	9.88	10.34	14.51	13.14	8.23	10.73	10.18	7.23	14.37	11.93	15.42	13.90	12.53
9	21.73	12.92	16.56	22.16	22.99	22.62	22.58	16.36	24.75	21.61	17.77	14.25	14.13	17.80	17.72	25.24	15.93	29.62	56.09
10	18.62	11.89	11.96	19.55	21.14	19.52	17.42	15.24	21.07	18.91	16.75	19.21	12.30	13.93	17.72	17.86	14.98	23.32	42.46
11	17.61	13.10	20.62	18.26	18.84	17.84	16.48	13.72	15.56	17.39	14.38	17.05	11.71	11.34	15.92	19.61	12.81	21.81	40.48
DPHM																			
6	88,00	64.3	90.7	91.7	88.0	91.0	69.3	69.0	91.3	95.7	90.0	89.0	87.3	69.0	92.3	91.3	86.3	96.3	111.7
7	88.59	66.7	93.0	92.7	89.3	91.7	89.0	67.0	92.3	95.7	90.3	87.0	87.0	71.0	91.3	88.0	85.7	99.3	117.7
8	87.55	70.0	93.3	95.7	86.7	90.7	86.3	72.3	88.3	92.3	87.3	87.0	85.3	71.7	91.7	90.0	86.7	94.0	106.7
9	74.70	57.7	74.7	74.3	73.7	73.7	74.3	65.3	74.3	85.3	74.7	75.0	71.0	68.3	71.7	73.0	75.3	82.3	100.0
10	73.87	59.3	73.0	72.0	74.0	73.0	75.0	62.3	73.0	84.0	73.0	76.0	68.7	66.7	70.3	70.7	77.3	81.3	100.0
11	74.40	59.0	73.7	74.7	75.7	74.0	75.7	63.3	73.7	82.7	73.7	75.0	69.0	67.7	71.0	73.0	77.3	80.0	100.0

Table 12 (cont'd.)

LDW

6	3.53	2.57	4.45	2.57	2.34	3.27	3.25	2.51	3.50	3.70	4.10	3.43	3.03	3.40	4.22	3.67	5.39	3.47	4.74
7	3.56	2.15	3.69	4.44	3.56	4.22	3.26	3.04	3.62	2.69	4.43	3.02	2.57	2.67	3.84	3.09	5.15	3.90	4.58
8	3.32	2.88	3.61	3.34	2.97	4.00	2.52	3.11	3.73	2.75	2.70	2.86	2.91	2.58	4.23	3.37	5.45	2.69	4.11
9	5.30	3.42	3.87	5.18	5.07	5.59	4.87	4.53	5.30	6.07	4.22	3.38	3.46	5.98	4.72	5.82	4.36	7.18	12.40
10	4.16	3.26	2.83	4.04	4.47	3.74	3.72	3.40	3.98	4.37	3.55	3.67	3.08	4.56	3.81	3.53	4.07	4.90	9.85
11	3.82	3.22	4.29	3.69	3.44	3.84	3.09	3.86	2.96	3.98	2.84	3.75	2.75	3.34	3.34	3.78	2.95	4.60	9.04

SDW

6	3.21	2.37	3.45	2.85	2.47	2.63	3.04	1.93	2.92	3.69	3.44	3.50	2.77	3.03	4.03	3.15	5.02	3.03	4.49
7	3.33	1.94	2.64	4.12	3.57	4.20	3.68	1.85	2.96	2.80	4.18	3.40	2.38	2.24	4.21	3.46	4.65	3.41	4.22
8	3.10	2.41	2.30	3.14	3.37	3.95	2.47	2.28	3.55	2.69	2.54	3.27	2.66	2.05	4.46	3.41	4.44	2.50	4.24
9	5.43	2.87	4.10	5.25	5.52	5.42	5.64	3.41	5.27	6.66	4.33	3.96	3.47	5.23	5.22	5.71	5.27	8.13	12.23
10	4.37	2.69	3.39	4.13	4.97	3.74	4.14	2.53	3.82	5.63	3.45	4.43	3.04	4.07	4.01	3.54	4.28	6.21	10.02
11	3.92	1.85	3.96	3.97	3.88	3.35	3.66	2.50	2.93	4.83	3.19	4.26	2.61	2.98	3.69	4.46	3.55	5.17	9.74

PDW

6	10.16	7.57	8.09	8.33	8.30	10.68	10.61	11.46	11.42	10.59	15.57	9.78	10.63	6.17	8.69	10.43	9.59	6.99	18.08
7	9.09	4.40	5.40	8.52	7.24	12.90	7.02	9.64	7.57	9.79	18.20	7.46	13.38	6.96	7.83	4.03	8.62	7.41	17.21
8	6.94	6.93	3.23	8.25	6.80	10.77	5.77	9.37	5.18	5.77	10.60	7.32	9.03	6.98	6.56	4.86	7.61	3.75	6.22
9	17.38	12.18	22.69	19.93	17.64	14.80	18.51	18.76	18.89	19.50	19.19	27.80	8.44	16.20	11.28	14.49	19.41	23.13	10.00
10	9.89	8.48	10.38	10.38	10.02	9.40	11.37	10.04	9.87	12.36	10.26	11.28	7.28	7.97	9.33	8.61	9.28	16.73	5.00
11	8.28	7.18	12.60	5.86	9.02	5.72	6.41	10.60	6.70	10.58	10.82	11.10	4.54	7.13	7.60	6.61	11.01	12.59	3.00

DM

6	118.09	97.3	122.0	121.3	117.3	124.7	117.3	101.3	116.0	130.3	121.3	116.3	115.3	97.3	124.0	118.3	119.3	124.7	141.7
7	117.99	98.3	122.7	124.7	118.0	123.3	116.7	98.0	116.7	127.3	120.0	117.0	117.7	96.7	122.0	117.0	119.7	126.3	141.7
8	118.39	99.1	131.3	124.7	116.0	123.3	118.0	100.0	118.0	121.3	123.3	117.0	119.0	96.0	121.3	123.3	120.0	122.7	136.7
9	96.13	77.0	98.3	92.0	95.0	92.7	93.7	87.3	93.0	114.7	92.0	98.0	94.3	86.3	89.3	91.0	99.7	106.0	130.0
10	92.42	75.0	94.0	85.3	90.0	90.7	92.0	80.0	92.0	111.0	92.0	95.3	84.3	82.0	86.3	84.0	97.0	102.7	130.0
11	93.01	75.7	93.7	85.7	91.0	93.0	91.7	83.7	91.7	107.7	92.3	95.0	86.0	82.7	89.3	84.3	99.3	101.7	130.0

Table 12 (cont'd.)

Yield

6	1532	1074	1319	1002	1402	2269	1656	1455	1615	1817	1811	1800	2032	1088	1280	1295	1434	1001	2229
7	1267	593	922	953	1507	1997	1269	1493	1324	1132	1762	1177	2182	905	1078	824	1104	1091	1489
8	940	1116	308	811	1145	1762	1069	1177	983	869	870	766	1181	917	723	779	1097	504	838
9	2873	2303	3138	2997	3184	3306	3216	2946	2984	2115	2620	3482	1982	2732	2868	3618	2928	3648	1657
10	1338	1219	1599	1268	1476	1354	1259	1355	1141	1291	1371	1260	940	1586	1526	1309	1364	1884	882
11	1059	938	1335	859	996	1228	1258	1332	907	712	1309	1198	707	1171	1268	894	1013	1360	562

X

6	10.17	10.5	9.3	11.5	9.7	10.7	12.5	10.2	10.2	11.2	13.7	9.1	15.4	3.9	8.0	15.7	10.2	6.8	4.1
7	9.63	5.7	8.3	11.6	11.5	16.6	9.6	9.9	8.5	11.0	18.0	9.7	14.3	5.4	6.8	5.6	9.1	8.0	4.8
8	8.37	10.2	4.2	12.0	10.2	13.6	8.6	11.3	6.7	6.5	10.8	8.7	13.8	5.3	7.0	7.8	7.4	4.6	1.9
9	13.87	11.9	15.9	18.3	17.0	12.4	17.1	16.0	15.1	16.5	15.5	20.3	11.9	8.7	8.3	13.8	14.1	14.4	2.5
10	8.66	8.1	8.6	11.0	9.7	8.1	11.7	9.0	8.3	10.0	8.1	10.8	10.5	5.4	7.1	9.8	7.2	10.9	1.5
11	7.25	6.4	9.5	6.4	9.5	5.9	7.6	10.0	5.9	8.0	8.2	10.0	7.1	5.4	5.6	7.3	6.9	9.8	1.0

Y

6	5.18	4.5	5.5	5.1	4.8	5.4	5.1	5.5	5.6	5.7	5.2	5.0	5.4	3.4	5.2	5.1	5.5	5.5	4.8
7	5.06	4.9	5.2	5.4	4.2	5.3	5.1	5.4	5.5	4.7	5.3	4.9	5.3	4.3	5.6	4.8	4.5	5.6	5.2
8	4.83	4.4	5.1	4.5	5.2	5.7	4.4	5.1	4.8	5.5	5.4	3.8	4.9	3.2	4.9	4.8	4.5	5.6	5.1
9	5.81	5.6	6.6	5.7	5.4	6.3	5.6	5.7	6.0	6.7	5.9	5.3	5.4	4.6	5.8	5.8	5.7	7.2	5.3
10	5.60	5.7	6.2	5.9	4.9	6.0	5.2	5.7	5.6	6.2	6.2	5.0	5.6	4.1	5.9	5.4	5.3	7.0	5.0
11	5.59	5.6	6.3	5.9	5.1	5.4	5.0	5.7	6.0	6.5	6.3	5.2	4.4	4.2	6.1	5.8	5.5	6.6	5.0

Z

6	22.79	18.5	19.3	17.4	18.6	18.3	17.8	19.7	18.4	20.3	22.4	24.4	16.5	42.3	19.1	15.0	22.1	19.1	61.0
7	22.73	18.5	18.7	17.9	18.6	18.7	17.3	19.8	18.9	19.6	23.2	24.5	17.3	41.6	18.3	14.5	21.9	21.8	57.9
8	22.77	18.6	19.1	18.6	20.9	18.7	18.5	19.3	17.3	19.8	23.8	23.8	17.7	44.0	17.8	17.0	23.2	17.4	54.4
9	24.63	20.2	21.7	20.0	21.5	21.4	20.2	23.3	22.0	19.1	21.3	25.6	17.3	47.3	22.4	19.8	28.5	21.8	50.0
10	24.00	20.1	21.3	18.5	21.3	20.9	21.3	21.3	21.5	19.0	23.9	24.6	16.9	46.0	21.5	18.3	27.7	20.9	47.0
11	23.63	18.7	20.9	18.3	20.2	20.9	21.2	21.7	21.3	20.2	24.5	24.9	18.2	41.5	20.6	17.7	28.9	20.7	45.0

Table 12 (cont'd.)

CH																			
6	45.07	32.3	30.0	41.7	35.7	42.7	39.7	33.3	37.7	54.0	40.0	43.7	36.3	35.0	45.7	43.3	36.3	50.6	133.3
7	45.74	40.7	36.3	48.0	51.0	45.7	45.0	37.7	43.0	47.7	48.3	35.3	45.7	35.0	52.0	39.3	39.3	43.3	90.0
8	43.04	43.3	32.7	46.7	44.7	49.3	43.3	39.0	47.0	38.7	44.0	30.0	38.7	41.3	48.7	44.3	32.0	39.0	72.0
9	70.68	41.7	120.0	53.3	50.0	49.2	54.8	44.2	45.8	111.7	39.2	115.0	39.2	52.5	51.7	49.1	54.0	120.8	180.0
10	65.25	49.0	73.3	60.8	68.3	33.6	65.8	59.3	57.7	77.5	70.0	71.8	47.0	53.3	69.2	57.5	68.3	94.3	97.8
11	85.60	63.2	104.2	74.2	70.8	66.7	85.7	59.2	72.5	116.7	105.0	97.5	64.2	53.3	94.0	60.8	89.2	116.7	146.7