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Plant Population Effects on the Seed Yield Components of Beans[1]

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ABSTRACT

Knowledge of the effect of plant populations on the seed yield components of beans (*Phaseolus vulgaris* L.) is needed to design management systems utilizing the genetic potential of different cultivars and to aid in the development of higher seed-yielding cultivars. The objectives of this study were to evaluate (a) the effect of different plant populations (area/plant) on the seed yield components as related to seed yield/plant, and (b) the relative differences between determinate ('Canyon', and 'Blue Lakes 274') and indeterminate ('UI-114', and 'Big Bend') bean cultivars. Seed yield/plant and the seed yield components were measured on plant populations from 107,600 to 968,700 plants/ha (100 to 930 cm²/plant) grown in a systematic design. Data were evaluated by path coefficient analysis based on correlations calculated from logarithmically transformed data. Pods/plants increased linearly as area/plant increased (decreasing plant population) for all cultivars studied, and had the largest effect on seed yield/plant. Seeds/pod and g/seed also increased as area/plant increased for the indeterminate cultivars, but remained relatively constant for the determinate cultivars. As a result, the seed yield/area is relatively constant over a wide range of plant populations for the indeterminate cultivars, but decreases at the smaller plant populations for the determinate cultivars. It also indicates that the determinate cultivar is subject to less competitive stress than the indeterminate one at the higher plant populations. The greatest potential for seed yield increases in high plant populations is with determinate cultivars.

Additional index words: **Seed yield, Indeterminate cultivar, Determinate cultivar, *Phaseolus vulgaris* L.**

YIELDS of many agricultural field crops have been increased by the adoption of improved cultural practices and higher yielding cultivars. However, the seed yields of beans (*Phaseolus vulgaris* L.) have not increased significantly in the last decade, although snap bean pod yields have been increased by increasing the plant population in more equidistant plant arrangements (3, 16).

The seed yield of beans is the result of many plant growth processes which are ultimately expressed in the yield components of pods/plant, seeds/pod, and g/seed. The highest seed yields are obtained when all are maximized. However, compensation for yield component may prevent large changes in seed yields because of negative correlations between yield components from intraplant competition for nutrients and metabolites (1). Knowledge of these interrelationships is, therefore, important for the development of high-yielding cultivars and would also be helpful in designing management systems utilizing the genetic potential of different cultivars. Several workers (5, 7, 12, 13, 19) have used the path coefficient analysis technique to study the interrelationships among seed yield components, but few studies have evaluated the correlations between components as affected by plant populations.

Recent data indicated that the seed yields of determinate (but not indeterminate) bean plant types could be increased by higher plant populations in equidistant plant arrangements (4). The objectives of this paper were to evaluate the effects of plant populations on the seed yield components of determinate and indeterminate cultivars.

MATERIALS AND METHODS

A description of the experimental conditions has been given previously (4). Briefly, two determinate ('Canyon', 1972, and 'Blue Lakes 274', 1973, bush snap beans) and two indeterminate ('UI-114', 1972 an 1973, and 'Big Bend', 1973, semi-vining field beans) cultivars were grown at plant populations from 107,600 to 968,700 plants/ha (100 to 930 cm²/plant). A systematic design (18) was used where the positions of the plants were determined by the intersections of radii and arcs of concentric circles. The growing area occupied by each plant was approximately square, and the area/plant increased systematically as the radius increased. One concentric-row circle of plants separated two yield concentric-row circles for each plant population. One complete circle area (360°) was planted to a cultivar, with three replications/cultivar in 1972 and 2 replications/cultivar in 1973. Growing conditions were maintained near optimum (4).

A wedge-shaped area consisting of 20 consecutive plants/plant population was selected from each replication at physiological maturity for the yield component analysis. The following traits were recorded: a) seed yield/plant, b) pods/plant, c) seeds/pod, and d) g/seed. Five consecutive plants from each plant population were also sampled at early bloom in 1973 for aboveground dry matter production.

Simple linear correlation coefficients were obtained between all recorded traits and seed yield/plant. We also analyzed correlations between logarithmically transformed data for each cultivar and year using Wright's path coefficients (23), as illustrated by Dewey and Lu (5). The model used is shown in Fig. 1. A path coefficient is a standardized, partial-regression coefficient that measures the direct influence of one variable upon another and permits the separation of the correlation coefficient into direct and indirect effects. For more information, see Li (15).

RESULTS

The simple linear correlation coefficients listed in Table 1 relate the seed yield/plant to each independent variable within cultivar and year. All independeint variables were positively related to the seed

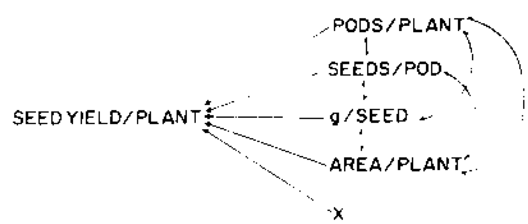

Fig. 1. Path diagram of the path coefficient analysis used where seed yield/plant was the dependent variable and pods/plant, seeds/pod, g/seed, and area/plant are the independent variables. The X variable consists of all residual factors that ininfluenced seed yield/plant not accounted for by the independent variables plus sampling error.

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yield/plant for the indeterminate cultivars, Big Bend and UI-114. Pods/plant and area/plant for both determinate cultivars, seeds/pod for Blue Lakes 274, and g/seed for Canyon were also positively related to seed yield/plant. Correlations between years for UI-114 were similar.

This analysis (Table 1) suggests that the contribution of yield components to seed yields depended upon the cultivar, and it illustrates the difficulty of identifying the significant yield components by this technique. The significant relationship between area/plant and seed yield/plant for all cultivars also suggests that some of the yield components are influenced by the area/plant. The area/plant was significantly related to pods/plant for all cultivars and to the seeds/pod and g/seed components for the indeterminate cultivars (Table 2). The yield components and area/plant effects on seed yield/plant were then separated with a path coefficient analysis (Table 3). The residual (X) is the path coefficient of the residual unaccounted for by the other pathways. The total correlation values given in Table 3 will differ slightly from those in Table 1 because of the logarithmic transformation of the data before the path coefficient analysis.

Table 1. Linear correlation coefficients between seed yield/plant and selected independent variables.

		Independent variables			
		Yield component			
Cultivar†	Year	Pods/plant	Seeds/pod	g/seed	Area/plant
		r			
D. Canyon	1972	0.991**	0.018	0.419*	0.979**
D. Blue Lakes 274	1973	0.994**	0.430*	−0.075	0.928**
I. Big Bend	1973	0.994**	0.942**	0.896**	0.994**
I. UI-114	1973	0.998**	0.868**	0.934**	0.964**
I. UI-114	1972	0.978**	0.655**	0.711**	0.965**

*,** Denote significance at the 0.05 and 0.01 probability levels, respectively.
† D = determinate, I = indeterminate.

Table 2. Linear correlation coefficients between area/plant and the respective yield components.

		Yield component		
Cultivar†	Year	Pods/plant	Seeds/pod	g/seed
		r		
D. Canyon	1972	0.976**	0.023	0.001
D. Blue Lakes 274	1973	0.984**	0.386	−0.068
I. Big Bend	1973	0.988**	0.944**	0.895**
I. UI-114	1973	0.982**	0.872**	0.947**
I. UI-114	1972	0.976**	0.604**	0.574**

** Denotes significance at the 0.01 probability level.
† D = determinate, I = indeterminate.

The total correlations between seed yield/plant and pods/plant were highly significant for all cultivars and years (Table 3). The path coefficients (direct effects) for this comparison ranged from 0.854 to 1.001. All indirect effects were small and positive for seeds/pod; positive for g/seed and negative for area/plant except for Blue Lakes 274 (where g/seed was negative and area/plant was positive). Pods/plant have also been shown to have the dominant effect on seed yields of *Phaseolus vulgaris* L. (7, 14), *Vicia faba* L. (10, 12, 24), *Vigna radiata* L. Wilczek (17), *Glycine max* L. Merr. (14, 17, 19), and *Lentilla lens* L. (22).

The total correlations between seed yield/plant and seeds/pod were small for the determinate cultivars and just significant ($P < 0.05$) for Blue Lakes 274; whereas all were highly significant ($P > 0.01$) for the indeterminate cultivars. All direct effects of seeds/pod were small and positive. The indirect effects were also small, except pods/plant for the indeterminate cultivars, indicating that the effect of seeds/pod on the seed yield/plant was largely via pods/plant, particularly for the indeterminate cultivars. The relationship between pods/plant and seeds/pod was positive and highly significant for the indeterminate cul-

Table 3. Path coefficient analyses of pods/plant, seeds/pod, g/seed, and area/plant upon seed yield/plant for cultivars and years.

	Cultivar and year				
Pathways of Association	Canyon 1972	Blue Lakes 274 1973	UI-114 1972	UI-114 1973	Big Bend 1973
Seed yield/plant vs. pods/plant					
Direct effect	1.001	0.954	0.854	0.854	0.905
Indirect effect via seeds/pod	0.002	0.030	0.090	0.086	0.088
Indirect effect via g/seed	0.052	−0.015	0.066	0.078	0.038
Indirect effect via area/plant	−0.068	0.001	0.026	−0.026	−0.035
Total correlation	0.987**	0.970**	0.984**	0.996**	0.996**
Seed yield/plant vs. seeds/pod					
Direct effect	0.055	0.170	0.168	0.107	0.107
Indirect effect via pods/plant	0.047	0.172	0.455	0.687	0.742
Indirect effect via g/seed	0.022	0.058	0.031	0.066	0.040
Indirect effect via area/plant	0.005	0.000	−0.014	−0.018	−0.029
Total correlation	0.129	0.400*	0.640**	0.842**	0.860**
Seed yield/plant vs. g/seed					
Direct effect	0.120	0.105	0.125	0.100	0.068
Indirect effect via pods/plant	0.131	−0.141	0.451	0.670	0.503
Indirect effect via seeds/pod	0.010	0.095	0.042	0.070	0.063
Indirect effect via area/plant	−0.030	0.000	−0.010	0.016	−0.019
Total correlation	0.531**	0.059	0.608**	0.856**	0.615**
Seed yield/plant vs. area/plant					
Direct effect	−0.070	0.001	−0.026	−0.022	−0.035
Indirect effect via pods/plant	0.977	0.939	0.833	0.839	0.894
Indirect effect via seeds/pod	0.004	0.014	0.093	0.088	0.090
Indirect effect via g/seed	0.052	−0.010	0.048	0.072	0.037
Total correlation	0.963**	0.971**	0.948**	0.977**	0.986**
Residual (X)	0.105	0.029	0.024	0.018	0.246

*,** Denote significance for total correlation coefficient at the 0.05 and 0.01 levels of probability, respectively.

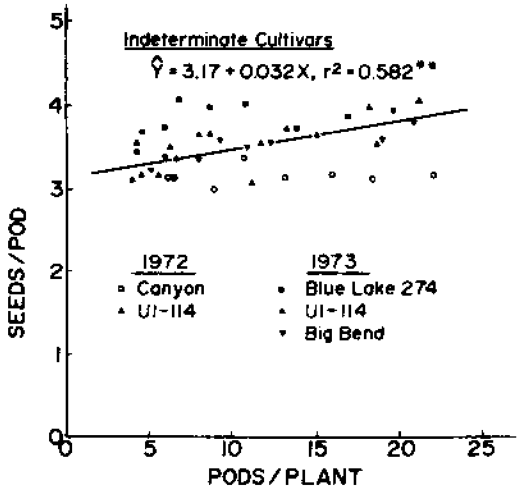

Fig. 2. Relationship between seeds/pod and pods/plant for the indeterminate cultivars; significant at 0.01 probability level. Regression coefficient for the determinate cultivars was not significantly different than zero.

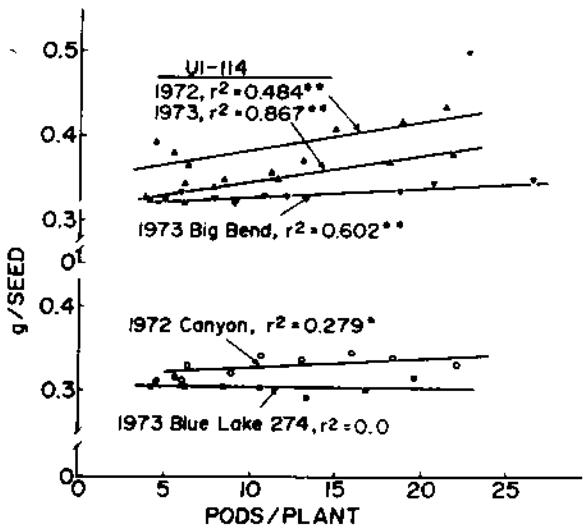

Fig. 3. Relationships between g/seed and pods/plant for each cultivar. *, ** denote significance at the 0.05 and 0.01 probability levels, respectively.

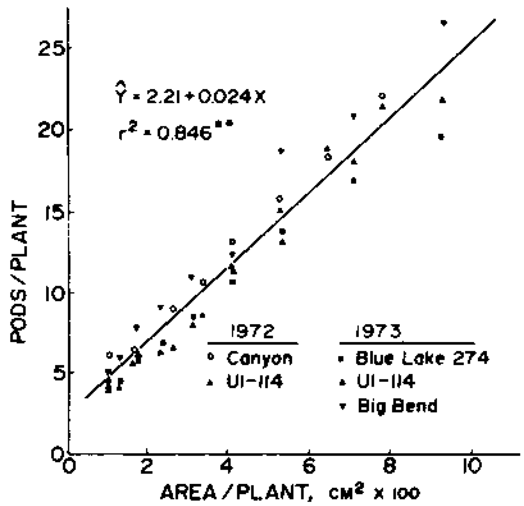

Fig. 4. Relationship between pods/plant and area/plant. Regression line includes all points from all cultivars; significant at 0.01 probability level.

tivars (Fig. 2). Agreement was good between the indeterminate cultivars. No correlation was found for the determinate cultivars.

The average g/seed was significantly correlated to the seed/yield plant for all cultivars, except Blue Lakes 274 (Table 3). Direct effects of the g/seed component were small and positive for all cultivars. The major portion of the total correlation resulted from the indirect effect of pods/plant. This occurred because g/seed increased as pods/plant increased (Fig. 3) and the relationship was significant ($P < 0.05$) for all cultivars, except Blue Lakes 274, for which no correlation was found. The slopes of the regression lines between g/seed and pods/plant for UI-114 were similar both years (Fig. 3).

The area/plant was significantly related to seed yield/plant for all cultivars (Table 3); however, all direct effects were small and usually negative. The important indirect effect was pods/plant, which was linearly related to area/plant for all cultivars (Fig. 4). Since the relationships were similar for all cultivars, only a single regression line including all cultivars is shown. Individual r values for each cultivar have been given in Table 2 for comparison.

DISCUSSION AND SUMMARY

The components of bean seed yield are believed to be genetically independent because correlations between components are essentially zero in noncompetitive studies. Yield component changes are believed to result from the plant's response to its environment, which may or may not allow the full genetic expression of each component (1). One concludes, then, that correlations between components are primarily from environmentally induced relationships.

Negative correlations can occur when developing plant structures compete for a limited energy supply (1) and can be induced by water stress (20), defoliation (6), removal of reproductive flowers (21), or removal of pods (1). They have also been shown to occur in natural selections of F_4 families (7), but were small and positive in parental and derived generations of *Phaseolus vulgaris* L. (2). Possibly we did not observe any significant negative correlations between the yield components in this study because the comparisons were restricted to a cultivar-year across plant populations. Also, no negative correlations would result if net photosynthesis changed proportionally to changes in plant size and the relative competition of the vegetative and reproductive sinks for assimilates were the same in all plant populations of a cultivar. Plant dry weights at early bloom and seed yield/plant in 1973 were lineary related (Table 4).

The different responses of seed yield/plant to area/plant may be explained on the basis of seeds/pod and seed weight, since the relationships between pods/plant and area/plant were similar for all cultivars (Fig. 4). The indeterminate cultivars maintained their seed yields/area at the lower plant populations by increasing the seeds/pod and g/seed, as well as their

Table 4. Linear coefficients between plant weight at 0.1 bloom and selected independent variables in 1973.

Cultivar	Independent variable				
	Area/plant	Seed yield/ plant	Pods/plant	Seeds/pod	g/seed
	r*,**				
Blue Lakes 274	0.915	0.885	0.916	0.215	−0.254
Big Bend	0.974	0.970	0.966	0.860	0.660
UI-114	0.843	0.861	0.881	0.662	0.585

*,** Correlation coefficients exceeding 0.300 and 0.605 are significant at the 0.05 and 0.01 probability levels, respectively.

pods/plant; whereas the seed yields/area of the determinate cultivars decreased at populations less than 300,000 plants/ha because seeds/pod and g/seed remained relatively constant. This data resembles that reported with other *Phaseolus vulgaris* L. cultivars (8, 20). In contrast, research with *Glycine max* L., Merr. (17, 19) *Vigna radiata* L. Wilcrzek (17), *Lentilla lens* (22), and *Phaseolus vulgaris* L. 'Savi' (14) has shown no effect of plant population on seeds/pod and g/seed.

Comparisons of dry matter accumulation in the plant components of *Glycine max* L. (9) showed that the indeterminate plant produced more vegetative growth during flowering and pod set than did the determinate plant. If this also occurs in the *Phaseolus* species, the potential for competition between the vegetative and reproductive sinks for photosynthate could be greater in the indeterminate than in the determinate plant. The indeterminate may compensate by producing fewer flowers per day over a longer flowering period or higher total photosynthate production. Increasing plant populations causes greater interplant competition, which could further increase the intraplant competition for assimilates. This effect may be larger for the indeterminate plant where there is a potential for greater competition between vegetative and reproductive growth. Data from a study conducted with *Vicia faba* L. (an indeterminate plant) support this, since it showed that proportionately less dry matter accumulated in the seeds and pods as compared with the vegetative plant parts when the plant population increased (11). In addition, we found that, as the plant population increased, the harvest index (dry weight of seed/total plant dry weight) decreased for the indeterminate cultivar UI-114, but remained relatively constant for the determinate cultivar Canyon (4). This indicated that proportionately more photosynthates went to seed production instead of vegetative production as the area/plant increased (decreasing plant populations) for the indeterminate but not for the determinate cultivars, and may help explain why seeds/pod and g/seed, as well as pods/plant, increased as area/plant increased for the indeterminate plant.

In summary, the pods/plant had a major effect on seed yield/plant for all cultivars across a wide range of areas/plant (plant populations). Yield differences between cultivars were due to differences in seeds/pod and g/seed, since both parameters decreased for the indeterminate but not for the determinate cultivars as the area/plant decreased. These relationships indicate that the determinate plant is subject to less competitive stress than the indeterminate plant types at higher plant populations. Full genetic expression of seed yield would be expected for the indeterminate cultivar at the lower plant populations, whereas it appears independent of plant populations for the determinate cultivar.

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