extended by Compton (10), might aid in attempts to recombine the different physiological and morphological components of yield. It remains to be seen if higher yielding recombinants can be obtained through physiological and morphological complementation.

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Effects of Between-row Spacing, Cultivation, and Genotype on Growth and Yield of Black Beans[1]

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Additional index words. Phaseolus vulgaris, lodging, roots

Abstract. **Two lines of black bean (*Phaseolus vulgaris* L.), '70001' and 'Strain 39', were grown at between-row spacings of 76, 61, and 46 cm. Cultivation treatments included an uncultivated check and a single cultivation at 1 of 3 plant growth stages: first trifoliolate leaf fully expanded; anthesis; or pod elongation. Root weight, shoot weight, and shoot:root ratio of individual plants decreased linearly as between-row spacing decreased. Biological yield increased linearly as between-row spacing decreased, but seed yield and harvest index did not show significant responses to spacing. None of the measured parameters gave a significant response when the uncultivated control was compared with the average of the 3 time-of-cultivation treatments. Root weight of individual plants and biological yield gave quadratic responses within the 3 time-of-cultivation treatments, both decreasing most markedly with cultivation at the pod elongation stage. Plants of '70001' were larger and lodged less compared to those of 'Strain 39'. Seed yields of both lines were similar. Results suggest that a single shallow cultivation may be used for black beans grown in narrow rows through anthesis. Although cultivation at the pod elongation stage was generally not detrimental to seed yield, it is not recommended.**

Recent developments in herbicide technology have reduced the need for mechanical weed control in dry beans and created interest in increasing the plant population per area in an effort to raise yields. Rows still need to be wide enough to permit cultivation if the chemical used fails to control all species of weeds which are present in significant numbers (16). However, crops grown with relatively narrow rows often require no more than a single cultivation in addition to an herbicide treatment for satisfactory weed control (9). This effect has been attributed to the increased competition experienced by the weeds (16). Further, shallow cultivation sometimes increases crop yields even when few or no weeds are present, particularly on soils prone to crusting, by improving moisture infiltration and soil aeration (9, 10).

Several studies with soybeans [*Glycine max* (L.) Merr.] (2, 9, 16, 17) and snap and dry beans (*Phaseolus vulgaris*) (3, 7, 8, 18) have demonstrated the potential for increased yields with narrow between-row spacings. Cultivars have been found to differ in

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their response to plant population density in these and other studies (1, 4, 5). Some researchers have attributed this differential response to plant morphological characteristics. It has been reported that the greatest potential for seed yield increases with high plant populations is with determinate cultivars (4). Seed yield pei area was relatively constant over a wide range of plant populations for semi-vining cultivars, but decreased at lower plant populations for determinate cultivars which lacked the ability to compensate for the increased area per plant (4). Other workers, however, do not accept the hypothesis that one particular plant type is needed for maximum yield in narrow rows (6, 13). One area of general consensus is the need for lodging resistance in cultivars being grown with high plant populations, since lodging tends to increase in dense plantings (2, 5, 17).

The present studies were conducted to compare '70001', a lodging-resistant breeding line, with a standard black bean cultivar at 3 between-row spacings. An additional objective was to evaluate the effects of a single cultivation at 1 of 3 plant growth stages.

Materials and Methods

The experiments were conducted on an Eel silt loam soil at the Homer C. Thompson Vegetable Research Farm, Freeville, N.Y., during the 1979 and 1980 growing seasons. In 1979, fertilization consisted of a broadcast application of 105, 46, and 88 kg/ha of N, P, and K, respectively. A similar procedure was used in 1980, but rates were changed to 162, 71, and 135 kg/ha of N, P, and K, respectively. Following fertilization in both years, EPTC (7E) (4.7 liters/ha) and trifluralin (4E) (1.2 liters/ha) were incorporated prior to planting. The herbicides completely controlled grasses and reduced broadleaf weeds to a few scattered plants. Seeds were treated with a diazinon-captan-streptomycin sulfate dust before planting. Carbaryl and dimethoate were used as required for insect control during the growing season. Foliar fungicides were used once each year: benomyl (50% WP) (2.2 kg/ha) was sprayed on Aug. 8, 1979, and maneb (80% WP) (2.2 kg/ha) was sprayed on Aug. 13, 1980. Overhead sprinkler irrigation was also used once each year: 2 cm of water were applied on July 22, 1979, and 3 cm of water were applied on July 24, 1980.

A split-split-plot design with 4 replications was used in both years. Between-row spacings were assigned to main plots, cultivation treatments to sub-plots, and genotypes to sub-sub-plots. The between-row spacings used were a standard of 76 cm (30 inch) and 61 cm (24 inch) and 46 cm (18 inch). Seeds within rows were spaced at 5 cm (2 inch) and thinned to 10 cm (4 inch) shortly after emergence. Cultivation treatments were an uncultivated check and a single cultivation at 1 of 3 plant growth stages: frist trifoliolate leaf fully expanded; anthesis (all plants with one or more blossoms); and pod elongation (majority of pods 2 to 5 cm in length). The latter 2 stages occurred about 3 and 6 weeks, respectively, after the first trifoliolate stage. Genotypes were '70001', one of the black-seeded breeding lines which were bulked to produce the recently released cultivar 'Midnight' (11), and 'Strain 39', a standard black bean cultivar. The breeding line was derived from a single plant having large roots and an upright growth habit.

In 1979 the lines were hand-planted on June 4 in 3-row plots which were 12.2 m long (6.1 m per genotype). The center row of each 6.1-m plot was further divided into a 2.7-m section for root excavations and a 3.4-m section for lodging ratings and yields. A similar planting plan was followed in 1980, but plot lengths were 9.8 m (4.9 m per genotype), with a 1.2-m section for root excavations and a 3.7-m section for lodging ratings and yields. The planting dates were June 16 and 17.

Cultivation treatments utilized 15-cm sweeps which were attached to the tool bar of an 'Allis Chalmers G' tractor with 147 cm between its wheels. There was one sweep on each side of the treatment row at the 46-cm row spacing, 2 sweeps on each side at the 61-cm spacing, and 3 sweeps on each side at the 76-cm spacing. In each case, however, the distance from the center of the treatment row to the point of the nearest sweep was 23 cm. The sweeps ran at an average depth of 6.5 cm. The wheels of the tractor were bracketed by guard rows at the 46- and 61-cm row spacings, and cultivation was accomplished in one pass. Because of equipment limitations, it was necessary to cultivate the 76-cm rows on one side at a time, with one tractor wheel between the guard row and the treatment row. At no time were the tractor wheels closer than 56 cm to a treatment row.

Root and shoot measurements were taken from 2 plants chosen at random in each plot. Plants were excavated with a spade at a 20-cm radius around each plant to a 20-cm depth. Roots were soaked in water and washed to remove the soil. Roots and shoots were separated and oven-dried, and dry weights were determined. The root excavations took place at the full pod-fill stage (majority of pods with full-sized seeds), which was about 3 weeks after the pod elongation stage.

Subjective lodging ratings were made just prior to harvesting using a scale of 1 (erect) to 5 (prostrate). Ratings were made by 2 persons working independently and were averaged, with a square root transformation being applied prior to analysis.

Plants from a 3-m section of each treatment row were hand-harvested and threshed to determine seed yield and biological yield. The latter was defined as roots + stems + pods + seeds. The harvest dates were Oct. 7, 1979, and Oct. 9, 1980. Samples were air-dried with seed yield adjusted to 18% moisture. Harvest index (HI) was calculated as (seed yield/biological yield) × 100. All data were subjected to combined analysis of variance over years.

Results

Effects of between-row spacing. Root weight, shoot weight, and shoot:root ratio of individual plants decreased linearly as between-row spacing decreased (Table 1). Root weight decreased relatively little between 76 and 61 cm but more markedly at the 46 cm spacing. The shoot:root ratios show that above-ground growth was reduced more due to narrow row widths than was root growth. Biological yield increased linearly as between-row spacing decreased, but the other yield parameters showed no significant responses to spacing (Table 2).

Effects of cultivation. No significant response was detected when the uncultivated control was compared with the average of the 3 time-of-cultivation treatments (Tables 1, 2). The primary reason for this was the tendency for a quadratic response within the 3 cultivation treatments. Also, there was less of an overall response to cultivation than to between-row spacing.

Root weight of individual plants decreased as a result of cultivation at the pod elongation stage compared with the 2 earlier cultivation treatments (Table 1). Shoot weight was not as greatly affected, however, and as a result no differences were found for shoot:root ratio. Biological yield gave a quadratic response within the 3 time-of-cultivation treatments, decreasing most markedly with cultivation at the pod elongation stage (Table 2). Seed yields followed the same trend, but the response was not significant. No differences could be shown for HI or lodging among cultivation treatments (Table 2).

Effects of genotype. The breeding line '70001' produced more robust plants than did 'Strain 39'. Plants of '70001' had heavier roots and shoots and a lower shoot:root ratio than plants of 'Strain

Table 1. Mean root weight, shoot weight, and shoot:root ratio as influenced by year, between-row spacing, time of cultivation, and genotype of black beans grown at Freeville, New York.

Treatment	Root wt[z] (g)	Shoot wt[z] (g)	Shoot:root ratio
Year			
1979	1.10	80.8	77.2
1980	1.35	87.0	66.7
Main effect	**	NS	NS
Between-row spacing (cm)			
46	1.08	68.8	66.7
61	1.27	84.0	70.1
76	1.32	98.8	79.2
S Linear	**	**	**
S Quadratic	NS	NS	NS
Time of cultivation (growth stages)			
No cultivation	1.19	83.2	73.2
First trifoliolate	1.29	87.1	70.8
Anthesis	1.28	84.6	70.3
Pod elongation	1.14	80.5	73.6
Control vs. Rest	NS	NS	NS
C Linear[y]	NS	NS	NS
C Quadratic[y]	**	NS	NS
Genotype			
70001	1.45	89.0	62.5
Strain 39	.99	78.8	81.4
Main effect	**	**	**

[z]Dry weights reported are totals based on 2 plants per plot.
[y]Within the 3 time of cultivation treatments.
*, ** Significant at the 5 and 1% levels, respectively.

39' (Table 1). The line '70001' also gave higher biological yields, and the plants lodged less than did plants of 'Strain 39' (Table 2). Seed yields of both lines were similar, but 'Strain 39' had a higher HI than '70001' (Table 2).

Differences between years. Individual plants which were harvested for root and shoot data were somewhat larger in 1980 than in 1979. While root weights were higher in 1980 than in 1979, the differences between years were not significant for shoot weight or shoot:root ratio (Table 1). Seed yield and biological yield were both lower in 1980 than in 1979, but HI and lodging were similar in both years (Table 2).

Plant number was not a factor in the analysis except between years. There was an average of 31 plants in the 3-m section of row used for harvest data in 1979, compared with an average of 29 plants in 1980.

Interactions. Genotype × spacing was significant for shoot weight because '70001' made its biggest decrease between 61 and 46 cm, whereas 'Strain 39' decreased more sharply between 76 and 61 cm. Genotype × year interactions were seen for root and shoot weight. Plants of '70001' were much larger than plants of 'Strain 39' in 1979, but in 1980 the 2 lines were more similar to each other, particularly for shoot weight.

Interactions were seen for both genotype × cultivation and genotype × cultivation × year for seed yield. The line '70001' did not exhibit the same response pattern in both years, but on the average cultivation had relatively little effect on its seed yield (Fig. 1). In contrast, 'Strain 39' showed a definite pattern that was the same in both years (Fig. 1). However, while cultivation at the pod elongation stage was the least beneficial of the 3 cultivation

Table 2. Mean seed yield, biological yield, harvest index, and lodging rating as influenced by year, between-row spacing, time of cultivation, and genotype of black beans grown at Freeville, New York.

Treatment	Seed[z] yield (kg/ha)	Biological[y] yield (kg/ha)	Harvest[x] index (%)	Lodging[w] rating
Year				
1979	3915	6786	57.9	3.0
1980	3017	5296	56.8	3.4
Main effect	**	**	NS	NS
Between-row spacing (cm)				
46	3575	6321	56.2	3.3
61	3433	6011	57.0	3.2
76	3390	5769	58.8	3.1
S Linear	NS	*	NS	NS
S Quadratic	NS	NS	NS	NS
Time of cultivation (growth stage)				
No cultivation	3387	5868	57.6	3.1
First trifoliolate	3558	6268	56.4	3.2
Anthesis	3535	6144	57.4	3.3
Pod elongation	3384	5854	57.8	3.3
Control vs. Rest	NS	NS	NS	NS
C Linear[v]	NS	NS	NS	NS
C Quadratic[v]	NS	**	NS	NS
Genotype				
70001	3499	6261	55.8	2.6
Strain 39	3433	5807	58.9	3.8
Main effect	NS	**	**	**

[z]Seed yields adjusted to 18% moisture.
[y]Biological yield = roots + stems + pods + seeds.
[x] Harvest index = (Seed yield/Biological yield) x 100.
[w]Lodging rating based on 1 (erect) to 5 (prostrate).
[v]Within the 3 time of cultivation treatments.
*, ** Significant at the 5 and 1% levels, respectively.

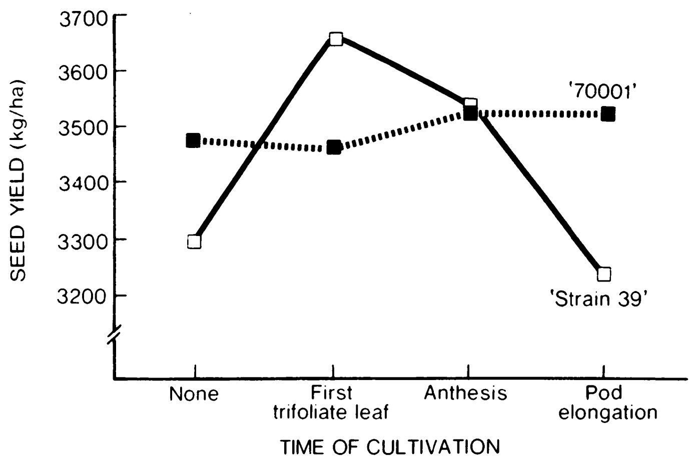

Fig. 1. The interaction of genotype and cultivation treatment on seed yield of black beans grown at Freeville, New York. Average of 2 years' data. A single cultivation was given at either the first trifoliolate leaf, anthesis, or pod elongation stage of plant growth.

treatments for 'Strain 39' in both years, it produced a sharp seed yield decrease from the control of 319 kg/ha in 1980. This compares with a 195 kg/ha seed yield increase over the control in 1979. The genotype × cultivation × year interaction for biological yield can be similarly explained. It should be noted that the biological yield of '70001' always exceeded that of 'Strain 39'.

While between-row spacing had no significant overall effect on lodging, a genotype × year × spacing interaction was seen. In 1979, neither line responded markedly to between-row spacing for lodging, but in 1980 'Strain 39' showed a steady increase in lodging ratings (that is, it became more prostrate) as spacing decreased.

The remaining interaction, genotype × cultivation × spacing for shoot weight, is complex and difficult to explain. It resulted at least in part from the genotype × spacing interaction already discussed.

Discussion

After reviewing numerous experiments, Kueneman et al. (7) concluded that, for a given density, planting beans in narrow rows at equidistant spacing generally resulted in higher yields than planting in rectangular arrangements. However, results varied from year to year and the yield advantage was not always statistically significant. In our studies, within-row spacing was held constant, so that the narrower rows resulted in higher plant populations per hectare (i.e., density increased). One may speculate that our trend towards higher seed yields per hectare at the narrow (61 and 46 cm) between-row spacings would have been more pronounced if similar densities had been employed. In addition, HI tended to decrease with decreasing between-row spacing. This indicates that the increase in seed yield was not proportional to the increase in vegetative growth obtained with the narrower rows. Further, both our cultivars were of the indeterminate, small-vine plant type. Indeterminate dry beans are able to compensate for the increased area per plant at lower plant populations (4). Thus, although such phenotypes have shown yield increases with narrow rows (1, 6, 8), the increases are often not statistically significant (6).

Cultivation at the first trifoliolate and anthesis stages did not reduce plant growth as compared with the uncultivated control. In fact, these treatments sometimes seemed to be beneficial, particularly with 'Strain 39'. Root growth appeared to have been stimulated by both cultivation treatments. While it is probable that little root pruning resulted, especially at the first trifoliolate stage, the increase in root biomass may have resulted from the regeneration of severed roots. It is more likely, however, that improvements in soil conditions were responsible — particularly the breaking up of the soil crust. This crust removal has been shown to be beneficial in cultivation experiments with soybeans on similar (silt loam) soils in other areas (9, 10).

Cultivation at the pod elongation stage was generally not beneficial, though with the possible exception of 'Strain 39' in 1980, it did not appear to cause injury relative to the control. Root weight of individual plants was less than that resulting from the 2 earlier cultivations (Table 1). Root pruning may have occurred. In addition, such a late cultivation would be less likely to give beneficial effects, because little root growth has been found to occur in black beans after the seed initiation stage (15). Thus, there would be little opportunity for root regeneration or for stimulated root growth due to improved soil conditions. The reduction in biological yield found when cultivation at the pod elongation stage was compared to the 2 earlier cultivation treatments also may be attributed to root injury and lack of root regrowth.

There are 2 possible explanations for the more pronounced seed yield response to cultivation of 'Strain 39' as compared with '70001'. First, '70001' may be less affected by soil-related stresses due to its inherently larger root system. Thus, if cultivation improved soil aeration and moisture infiltration as compared to the uncultivated control, 'Strain 39' would be more likely to show a response than would '70001'. Second, cultivation at the pod elongation stage in 1980 was clearly more detrimental to 'Strain 39' than to '70001'. The plants were larger in 1980 than they were at the corresponding time in 1979, in part because the 1980 treatment was delayed by 5 days due to inclement weather. The canopies of 'Strain 39' appeared to be more closed than those of '70001' at that time, perhaps because 'Strain 39' seemed to have longer runners which had begun to intertwine. As a result, plants of 'Strain 39' were contacted more than those of '70001' as the cultivator shanks moved through the rows. Lodging was not increased by this treatment, but it is probable that plants of 'Strain 39' lost more leaves and flowers than did those of '70001'. There was little shoot damage to either genotype with cultivation at the pod elongation stage in 1979.

The differences in response between years may be explained by the later planting date in 1980. A delay in planting has been shown to reduce yields of dry beans (1, 7). In addition, some plants were damaged by white mold [*Sclerotinia sclerotiorum* (Lib.) d By.] in 1980. Most diseased plants were found in the 46-cm plots. There did not appear to be differences in infection between the 2 lines. White mold problems have been noted in other bean spacing trials and have been most severe with high plant populations where reduced air movement and increased relative humidity within the canopy favor pathogen development (1, 3, 4).

The problem of increased lodging in dense bean plantings has already been noted (2, 5, 17). Lodging-resistant soybean cultivars have shown greater yield stability across populations (5), and it has been suggested that lodging-resistant cultivars may be better able to utilize higher plant populations and respond with increased yields (2). In this respect, '70001' is a more promising candidate than 'Strain 39' for high population plantings. It has consistently been more erect than 'Strain 39' in previous trials (14) and was also more erect in the present studies. Further, erect cultivars with pods high off the ground are particularly desirable for direct harvesting. While '70001' and 'Strain 39' were similar in yield potential when hand-harvested, '70001' might be expected to have a higher yield when mechanically harvested due to its ability to hold its pods well off the ground.

Growers who have wanted to try higher populations of dry beans, with an eye toward future direct harvesting, have been concerned about the ability to cultivate the narrow rows. Studies have shown that beans have a critical period, lasting up to about the fifth week after planting, during which they must be kept free of weed competition in order to avoid yield losses (12, 18). Peters et al. (9) reported that with narrow rows (51 or 61 cm) no more than one cultivation in addition to an herbicide was necessary for good weed control and high yields of soybeans. Russell et al. (10) obtained a similar result with soybeans spaced 68 cm apart. Our studies suggest that a single shallow cultivation treatment may be used through anthesis for black beans spaced as close as 46 cm apart. Although in these studies cultivation at the pod elongation stage was generally not detrimental to seed yield, it is not recommended. Large plants may be damaged by such a late cultivation, and seed yield decreases have been noted in other studies (10). Growers planting black beans in narrow rows can utilize this information if their herbicide fails to provide adequate weed control, or if their soil becomes hard and crusted.

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Growth Analysis of Two Tomato Genotypes Differing in Total Fruit Solids Content[1]

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Abstract. **Two tomato (*Lycopersicon esculentum* Mill.) genotypes, LA 1563, a high solids breeding line and 'VF145B-7879', an intermediate solids cultivar, were studied in an attempt to determine which morphological characteristics contribute to high solids content in the fruits, and to evaluate 1563 as genetic material for higher solids in processing tomato fruits. A genotypic difference in fruit solids was apparent from as early as 10 days after anthesis, and continued through fruit development. Between 10 and 50 days after anthesis, 1563 and '7879' fruits increased in mean dry weight from 0.057 g to 5.16 g and from 0.101 g to 4.28 g, respectively. A growth analysis showed that lower harvest index, lower fruit yield and larger leaf area were associated with the higher solids of 1563, compared to 7879.**

Increased solids in tomato fruits has become increasingly crucial to the tomato industry because of the rising cost of energy needed for transportation and processing. Therefore, one of the main goals of tomato breeders is to develop cultivars with higher fruit solids content. Considerable genotypic variation in solids content exists within tomato. Lambeth et al. (4) surveyed the soluble solids content of 175 *L. esculentum* lines and 25 *L. pimpinellifolium* lines and found soluble solids ranging from 4.1 to 8.9% and 4.9 to 9.2%, respectively. The physiological basis of this variation is not understood. Stevens and Rudich (8) reported that soluble solids content is inversely correlated with yield (r = –0.947)

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