J. Amer. Soc. Hort. Sci. 104(6):873–875. 1979.

Quantitative Relation of Bush Snap Bean (*Phaseolus vulgaris* L.) Yields to Plant Population Density[1]

J. R. Stang[2], H. J. Mack[2], and K. E. Rowe[3]
Oregon State University, Corvallis, OR 97331

Additional index words. yield-density models, nitrogen fertilization, snap bean

Abstract. **The yield-plant density relationships of 5 bush snap bean cultivars and the effect of rate of N application on the yield-density relationship of a single cultivar were studied in 2 separate experiments. Responses were described by the equation $W^{-\theta} = \alpha + \beta\rho$ where W is the pod weight per plant, ρ is the plant population density, and θ, α and β are constants. The θ, α and β values were tested for significant differences among the cultivars and levels of N. In experiment 1, $\theta = 0.836$ was acceptable for all 5 cultivars and in experiment 2, $\theta = 0.897$ was acceptable for the 3 rates of N. Values of θ were similar to those found for bush snap beans by other researchers. Significant differences existed among both α and β values of the cultivars. In the N experiment, α was constant but values of β differed significantly and were inversely related to the level of N. Optimum plant density was dependent on the cultivar and increased with the level of N.**

The relation of plant population density to the yield of bush snap beans has been examined in several studies; however, the results are difficult to compare because of differences in the range of densities, plant arrangements and methods of harvest. In addition, the usual method of interpreting the data, using tests of significant differences, does not facilitate the comparison of results from different experiments. Nelder (7) has criticized the use of tests of significant differences in such studies and advocated the use of quantitative models because the form of the relation of yield to increasing density is of primary interest rather than the significance of individual population differences. Bleasdale (1) proposed the following model to describe the form of yield-density relationships: $W^{-\theta} = \alpha + \beta\rho$ where W is the yield per plant; ρ is the plant density; and θ, α and β are constants. This model describes an asymptotic yield-density relationship (yield rises to a maximum and is relatively constant at higher densities) when $\theta=1$, and a parabolic relationship (yield rises to a maximum but declines at higher densities) when $\theta < 1$. Biological significance has been attributed to variation in α and β: α said to measure the genetic potential and β the yield potential of the environment (2, 8). The experiments reported herein were undertaken to describe the effects of cultivar and rate of N application on the yield-density relationship of bush snap bean using the Bleasdale model, and to analyze for constancy of θ and biological significance in the variance of α and β.

Materials and Methods

The systematic planting design type la of Nelder (6) was used. Because of their appearance, the units were referred to as fans. Plant arrangement was constant at a rectangularity of approximately 1:1 (square). To eliminate border effects, 2 guard rows were left at low densities and 3 at high densities. Data were collected from densities ranging from 21 to 110 plants m^{-2}.

In experiment 1, 5 bush snap bean genotypes were studied: 'Oregon 1604', 'Oregon 58', 'Gallatin 50', L-81 (developed by the New York Agricultural Experiment Station) and Keystone 4672 (developed by Keystone Seed Company, Hollister, California). The latter 2 lines were selected for their smaller leaves and more compact growth habit. Each genotype was planted in a separate fan and the experiment was replicated 3 times. All plots were harvested a single time on the same date. Pod yields are reported as dry weights (oven dry at 80°C from 48 to 72 hr).

In experiment 2, the effect of 3 rates of nitrogen fertilization on the yield-density relationship of 'Oregon 58' was investigated. N was broadcast at 0, 50 and 100 kg/ha of actual N as NH_4NO_3 prior to planting and rototilled into the top 10 cm of the soil. Each fan represented a different rate of N. The experiment was replicated 3 times. Pods were harvested a single time on the same date and yields were recorded as fresh weights.

A weighted least squares regression was used to fit an optimum response curve for each cultivar (5, 7). The curves were analyzed to determine whether differences among the θ, α and β values were statistically significant. The curves for each genotype or rate of N were compared according to the following modification of a procedure described by Mead (5):

1. fit α and β for each cultivar or N level using the best individual estimates of θ;
2. fit α and β for each cultivar or N level using the best common estimate of θ;
3. test for significance of difference among the θ values.

If a common θ was statistically acceptable, further tests were made using a common θ for:

4. all data sets using a common α and individual β values;
5. all data sets using a common β and individual α values;
6. all data sets using both common α and β values.

Results and Discussion

The crop was harvested, when about 70% of the pods were sieve size 4 or larger. Lower densities tended to have a slightly higher percentage of smaller pods, due to a longer period of pod set. This fact was not considered to be a limitation to the interpretation of the yield density relationships because the late setting pods would not contribute significantly to yield in the single, destructive harvests used in commercial bush snap bean production.

Mean yields per plant are presented in Tables 1 and 2. The results of fitting the θ, α and β and analyzing for variance among cultivars and among rates of N are presented in Table 3 and 4. The fitted values were used to prepare the curves presented in Figures 1 and 2, and to calculate the population density giving the maximum yield as

$$\rho \text{ opt} = \alpha\theta/\beta(1-\theta),$$

[1]Received for publication January 25, 1979. Oregon Agr. Expt. Station Technical Paper No. 5067. This study is part of a PhD thesis by the senior author.

[2]Department of Horticulture.

[3]Department of Statistics.

Table 1. Effect of plant density on the pod dry weights (g) per plant of 5 bush snap bean cultivars.

Plant density (plants/m²)	Pod dry weight (g) per plant				
	Oregon 1604	Oregon 58	Gallatin 50	L-81	Keystone 4672
21.1	15.10	12.66	9.32	8.12	7.59
25.4	13.65	13.07	7.20	9.23	7.59
30.4	12.42	11.03	7.91	7.08	6.54
36.6	11.35	9.17	6.97	7.32	6.39
43.9	8.95	8.33	5.26	6.90	5.93
52.7	8.25	7.93	5.29	5.56	4.62
63.4	6.62	6.08	3.86	4.78	4.05
76.2	7.34	5.36	3.41	3.95	4.49
91.4	5.11	5.11	3.10	4.03	3.41
110.0	4.20	3.69	2.51	3.37	2.93

Table 2. Effect of plant density and rate of N on the pod fresh weight (g) per plant of bush snap bean 'Oregon 58'.

Plant density (plants/m²)	Pod fresh weight (g) per plant: Rate of N		
	0 kg/ha	50 kg/ha	100 kg/ha
21.1	118.7	139.2	162.0
25.4	103.4	109.8	133.7
30.4	94.9	95.6	109.5
36.6	77.9	85.9	86.7
43.9	60.1	78.5	83.4
52.7	50.0	63.8	73.0
63.4	46.4	52.6	63.3
76.2	39.8	39.0	43.4
91.4	29.8	38.6	39.5
110.0	26.2	30.4	33.9

and the pod yield per plant at the optimum population density as

$$W \max = (1-\theta/\alpha)^{1/\theta}.$$

In the first experiment, the fit with $\theta = 0.836$ (mean of the individual values) for the 5 cultivars did not differ significantly from the fit with the individual values of θ. In the second experiment, the mean value of $\theta = 0.897$ was found to be acceptable for all 3 rates of N. Experience showed, however, that because of experimental error, a wide range of θ values gave statistically acceptable fittings. Nevertheless, values are similar to the $\theta = 0.896$ reported for bush snap beans by Nichols (8) and the values ranging from 0.792 to 0.933 reported by Rogers (9). These observations suggest that a θ between 0.8 and 0.9 may be an acceptable standard for bush snap beans.

A standard θ simplifies the use of the Bleasdale model to describe the yield-density response of snap beans. The detail of the computer fitting process is eliminated and the overall yield-density response of bush snap bean can be determined with data from fewer plant densities. In theory, with a standard θ, then α and β could be calculated from only two densities.

$\theta < 1$ indicates that the relation of pod yield to increasing plant density is parabolic, but Fig. 1 and 2 show that a wide range of densities gave yields near the maximum for a particular genotype or rate of N. The slightly parabolic response of bush snap beans to increasing plant density has been previously reported (4, 8).

In the second experiment, the values of β were found to be significantly different and inversely related to the level of N fertilization while α remained constant (Table 4). These results conform to the theory that β is a measure of the yield potential of the environment. Nichols (8) reported similar results for α and β in response to N fertilization.

In the first experiment, both α and β varied among the 5 cultivars (Table 3): this did not support the aforementioned theory. Jones (3) reported variation in both of these parameters in a comparison of the yield-density responses of 2 cultivars. Variation in β among cultivars may be related to differences in the abilities of genotypes to exploit a given environment for pod production.

Optimum population density depended on the cultivar. The smaller leaved and more compact lines, Keystone 4672 and L-81, had higher optimum plant densities; however, the yields of 'Oregon 1604' and 'Oregon 58' were superior at all densities investigated and were highest at ρ opt. The yield of 'Gallatin 50' was superior to that of the 2 compact lines at lower densities but was inferior at higher densities. The interaction has implications in plant selection because selecting for yield at a single low density may not give an indication of the yield potential of a genotype at high densities. Mack and Hatch (4) observed greater differences in yields among bush snap bean cultivars at higher densities than at lower densities. This was not generally the case in the present study.

The optimum plant density was directly related to the level of N fertilization up to the highest level investigated, 100 kg/ha. This result indicates that higher rates of N fertilization would be beneficial at higher plant densities and that more effective use of added N can be expected if plants are grown at higher densities.

Table 3. Fitted values[z] for 5 cultivars of bush snap bean.

Cultivar	Best fit: θ	Best fit: RSS[y]/θ^2	Values based on $\theta = 0.836$: RSS[y]/θ^2	α ($\times 10^2$)	β ($\times 10^3$)	ρ max (plants m^{-2})	W max (g dry wt per plant)	Y max (g dry wt/m²)
Oregon 1604	0.69	0.0521	0.0528	5.996	2.076	147.3	3.33	490.7
Oregon 58	0.76	0.0347	0.0349	6.612	2.304	151.0	2.96	447.7
Gallatin 50	0.84	0.0433	0.0433	8.409	3.495	122.7	2.22	272.7
L-81	0.86	0.0547	0.0547	11.112	2.348	241.3	1.59	384.4
Keystone 4672	1.03	0.0627	0.0634	12.668	2.560	260.4	1.36	354.7
Totals and (degrees of freedom)		0.2475 (35)	0.2491 (39)					

[z]Equations described in text.

[y]Residual sum of squares.

Table 4. Fitted values[z] for 3 levels of N fertilization.

N rate (kg/ha)	Best fit θ	Best fit RSS[y]/θ^2	Values based on θ = 0.897: RSS/θ^2	α (× 10^3)	β (× 10^4)	ρ max (plants m^{-2})	W max (g fr. wt. per plant)	Y max (g fr. wt/m^2)
0	0.90	0.0191	0.0191	3.67	4.66	68.8	41.1	2828
50	0.84	0.0254	0.0256	3.67	4.03	79.4	41.1	3264
100	0.95	0.0382	0.0386	3.67	3.58	88.5	41.1	3638
Totals and (degrees of freedom)		0.0827 (21)	0.0833 (23)					

[z]Equations described in text.
[y]Resdiual sum of squares.

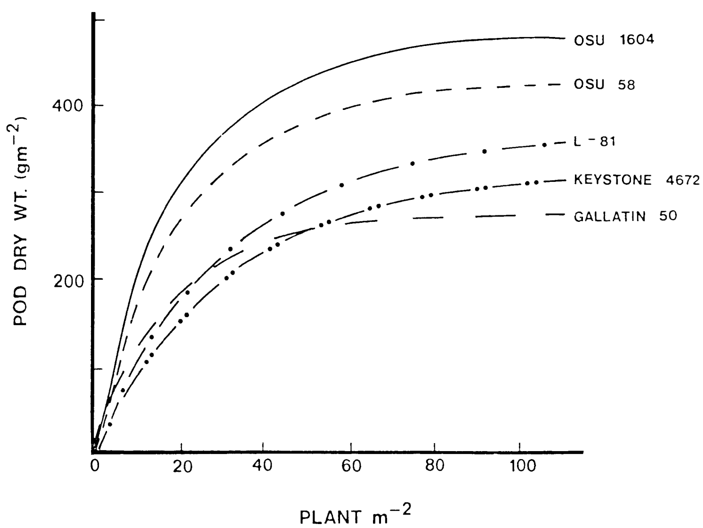

Fig. 1. Effects of population density on the pod yields of 5 bush snap bean cultivars.

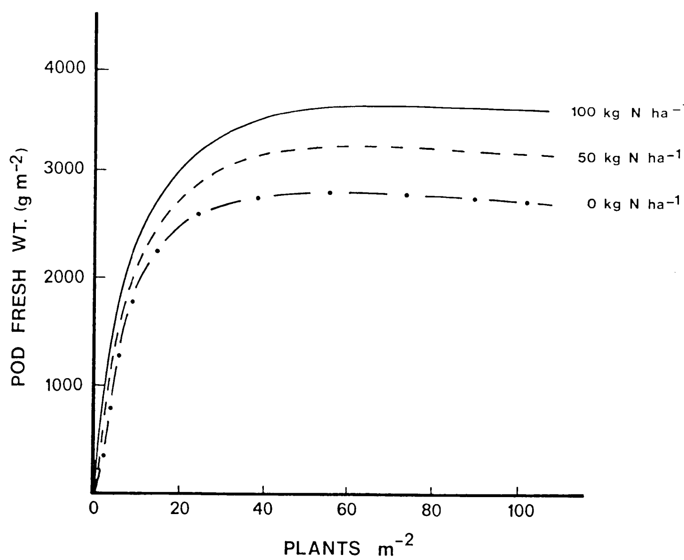

Fig. 2. Effects of population density and rate of N on the pod yields of Oregon 58 bush snap beans.

Literature Cited

1. Bleasdale, J. K. A. 1966. The effects of plant spacing on the yield of bulb onions (*Allium cepa* L.) grown from seed. *J. Hort. Sci.* 41:145-153.
2. __________ and R. Thompson. 1966. The effect of plant density and the pattern of plant arrangement on the yield of parsnips. *J. Hort. Sci.* 41:371-378.
3. Jones, L. H. 1967. Factors affecting the productivity of dwarf French beans. *Agric. Prog.* 42:32-52.
4. Mack, H. J. and D. L. Hatch. 1968. Effects of plant arrangement and population density on yield of bush snap beans. *J. Amer. Soc. Hort. Sci.* 92:418-425.
5. Mead, R. 1970. Plant density and crop yield. *Appl. Stat.* 19:64-81.
6. Nelder, J. A. 1962. New kinds of systematic designs for spacing experiments. *Biometrics* 18:283-307.
7. __________ . 1963. Yield-density relations and Jarvis's lucerne data. *J. Agric. Sci.* 63:427-428.
8. Nichols, M. A. 1974. Effect of sowing rate and fertilizer application on yield of dwarf beans. *N. Z. J. Expt. Agric.* 2:155-158.
9. Rogers, I. S. 1976. The effect of plant density on the yield of three varieties of French beans (*Phaseolus vulgaris* L.). *J. Hort. Sci.* 51: 481-488.