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Title: EFFECT OF PLANT POPULATION ON PLANT CHARACTERISTICS AND YIELD OF BUSH SNAP BEANS

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'Tendercrop' and 'OSU 949' green snap beans were grown at populations varying from 77,000 to 392,000 plants per acre with two row spacings and six square arrangements ranging from 4 x 4 to 9 x 9 inches. Maximum yield of 10.1 tons per acre (32 percent sieve size 4 and smaller) was obtained from 'Tendercrop' with a spacing of 7 x 7 inches or 128,000 plants per acre. 'OSU 949' produced the highest yield of 13.3 tons (31 percent sieve size 4 and smaller) at a spacing of 5 x 5 inches or 251,000 plants per care. Yields were significantly lower when plants were in 24 or 36 inch rows than when the same plant population was spaced 6 x 6 inches.

'OSU 949' appeared to be physiologically more efficient than 'Tendercrop' when plant stands were averaged, with 11 percent smaller plants producing 56 percent higher pod yields. The plant-pod ratio for the two varieties was 1.02 and 1.80, respectively.

The leaf area index of 'OSU 949' was less than 'Tendercrop,'

even though it yielded more. Plants grown in rows had a lower leaf area index than plants grown in a square arrangement.

When harvested at the same time, closer spacings tended to produce a higher proportion of smaller sieve-size pods.

Effects of Plant Population on Plant Characteristics and Yield of Bush Snap Beans

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EFFECT OF PLANT POPULATION ON PLANT CHARACTERISTICS AND YIELD OF BUSH SNAP BEANS

INTRODUCTION

Snap beans are a significant portion of the vegetable processing industry in Oregon. About 75-85,000 tons were canned and frozen annually during the 1955-1958 period, with a value to growers of 10-12 million dollars. Substantially all the production was from pole beans, especially of the stringless 'Blue Lake' type.

Since that time, increased labor costs for bean-yard erection and hand picking have caused a shift toward mechanically harvested bush beans. A dwarf or bush habit type with pod quality comparable to that of the 'Blue Lake' pole bean is needed. Problems such as those caused by the trash and clusters found in machine harvested beans will also be major considerations before there will be a complete change to bush beans.

The average yield of pole beans during the 1955-1958 period was 7.2 tons per acre. Picking costs were about $70 per ton. Present varieties of bush beans yield 2.5-4.0 tons per acre. Costs of harvesting by machine range from $20-25 per ton, depending mostly on yield. Production of bush beans, aside from quality factors, may have other disadvantages. Because of lower yields, more acres will be required to supply the same tonnage to the processors. The picking machines are expensive and can be used for bush beans only. Bush bean harvesters currently in use require rows spaced 36 inches apart.

Traditional methods of planting, cultivation and harvest of horticultural crops have dictated that these crops be planted in rows within which machinery or animals could move readily. This traditional method of planting does not necessarily promote the best growth and/or production of the desired usable portion of the plant. Recent advancements in herbicide usage and crop management have made mechanical weed control in many fields unnecessary. With these developments other planting arrangements can be considered in snap bean production.

Increasing population density through use of "bed culture" or growing plants without defined rows may have the potential for increasing yields. If this were the case, fewer acres could supply current needs. Since the cost of harvest per ton is largely a factor of yield, the grower might realize a substantial saving.

At the present time, machinery has not been developed that will harvest beans when planted in beds of narrow rows or in a solid stand. If this field growing method would prove to have advantages, development of suitable planting and harvesting equipment would be warranted.

This study was conducted to determine the effects of population density and plant arrangement on plant characteristics and yield of two bush bean cultivars.

REVIEW OF LITERATURE

Competition between organisms may influence their ability to produce the portion utilized for food purposes. Milne (13) has delved deeply into the meaning and use of competition as it pertains to the biological field (principally animals). "Competition is the endeavor of two (or more) animals to gain the same particular thing or to gain the measure each wants from the supply of a thing when that supply is not sufficient" (p. 57). An expanded definition, however, might include the statement

> . . . two plants, no matter how close do not compete with each other so long as the water content, the nutrient materials, the light, and the heat are in excess of the needs of both. When the immediate supply of a single necessary factor falls below the combined demands of the plant, competition begins (7, p. 3).

Davidson and Donald (6) suggest that factors for which a plant may compete include fertility, water, and light, with the latter being the most universal. Shortage of the others may influence yield, but the competition for light differs in several ways from those other factors needed for the growth of plants. Water and nutrients may be likened to a reservoir from which all competitors may draw. At times this supply may be almost limitless, but at other times it will be inadequate or varying such as in a soil fluctuating between field capacity and the wilting point. On the other hand, light energy is instantaneously available and if not instantaneously intercepted by leaves, it will be lost as a source of energy for photosynthesis. In fact, in a young crop this energy falling onto the soil surface promotes the problem of increased evaporation of water from the soil surface (18). Some of the most intense competition for light occurs within individual plants and as lower leaves are shaded by upper leaves, it may be so acute that leaves may die. Plants compete with each other for light and, except for newly emerged seedlings, this is a phenomenon present throughout most of their lives because it begins whenever one plant casts a shadow on another. In our manner of growing food crops in rows, adjacent plants in the row shade their neighbor at a very early stage of growth.

Baker and Meyer (2) tested various planting and row arrangements, including orientation of rows of cotton. Their findings indicated that regardless of plant size, sun angle, or planting pattern the growth rate was directly proportional to the amount of light intercepted.

Loomis and Williams (10) reported that for maximum crop production, important factors to consider included leaf area and arrangement, and carbon dioxide supply. Those of limited importance were storage or transport of photosynthates and chlorophyll content of the leaves. The carbon dioxide supply might reduce photosynthesis during the day when maximum respiration was occurring. Monteith (15) also presented figures suggesting that at times carbon dioxide may limit photosynthesis. This limitation generally would not cause more than a 10 percent average reduction and would be attributed to a local temporary deficit of carbon dioxide in the crop canopy.

When water and nutrients are in adequate supply, light will usually then become the limiting factor which controls rate of growth and total production of dry matter in a given crop (6). In production of horticultural crops, temporary stresses for water may develop, but nutrients are usually applied in adequate or excessive amounts so that light, which is largely taken for granted, is inadequate.

Studies with individual leaves indicate that their maximum photosynthetic rate may occur at 1,500 -2,000 foot candles. On a bright day, light intensities may exceed 8,000 foot candles, which one may consider excessive of plant needs. Much of the foliage of a mature plant is shaded by upper leaves, especially in a crowded stand. This shaded portion cannot approach its maximum functioning unless more light is transmitted through and around upper leaves. Monteith (15) worked out involved mathematical formulae to establish photosynthesis in crops based on light and other factors of weather. He emphasized the lower portion of the plant and indicated that the most effective area for photosynthesis is on the unshaded leaf plus the leaves once shaded.

Other factors which influence the plant itself must be considered. The greater the amount of leaf growth made before plants come into contact with each other, the more extensive the root system and the more drought resistant the plant will likely be (14). If the plants do not suffer from lack of water, this is of little importance; but the higher the density, the smaller is the root zone of the plant, and the lower the soil water deficit which is detrimental to plant growth.

Root patterns of corn were reported for various plant populations by Haynes and Sayre (8). Corn planted in 8.5-foot rows to assure no overlapping of roots was spaced from 64 inches to 1 inch apart in the row. The root pattern was circular as the spacing decreased from 64 to 8 inches in the row from which point it was oblong. As the plants were more closely crowded, the roots penetrated farther out into the center of the row, with the 1-inch spaced plants having lateral root growth of 41 inches. The roots spread about 16 inches down the row, demonstrating how much competition was created by overlapping roots under the row. Roots developed toward the row center where competition was less. Grain yield from this trial was highest at the 4-inch spacing. Total plant weight was highest at the 1-inch spacing, but not significantly more than at 4 inches.

Norden (16, 17) indicated that plant population had a great effect on corn root development in Florida. Increasing the population from 5,000 to 25,000 plants per acre caused a 72 percent decrease in dry matter weight of roots per plant. On an acre basis, however, root weight increased when populations were increased from 5,000 to 20,000 plants, but decreased 9 percent from the 20,000 to 25,000 plant population. Grain yield was not significantly different from 10,000 to 25,000, but the 5,000 plant population was about 20 percent less. This was despite a 73 percent reduction in individual plant grain yield as the population increased to 20,000 plants per acre.

Williams et al. (23) found that corn did not reach a peak of production spaced as closely as 6 x 3 inches. Light interception was only about 25 percent at a 48 x 48 inch spacing and a leaf area index (LAI) of 1.5, but the more dense populations intercepted 100 percent of the solar radiation with LAI values up to 20. Work by the same authors (10) confirms the fact that monocotyledonous plants probably display leaves more effectively for maximum light interception than do dicotyledonous plants. Davidson and Donald (6) indicated that subterranean clover reached a maximum effective LAI of about 4 or 5. At higher values lower leaves do not get enough light for photosynthesis greater than their respiration loss and, therefore, are "parasites" on the plant system. At very low LAI values (when the plant is young), even though all leaves are unshaded, the dry matter production will be low and will fall short of the maximum potential that the environment provides.

In experimenting with tall and short sorghum genotypes, Stickler and Younis (21) suggested that the reason tall sorghum performed poorly at high, but better at low plant population, was because the longer internodes gave less mutual shading with greater exposure of more leaf area to solar radiation. The light distribution was, therefore, more uniform throughout the entire plant leaf area. The dwarf genotype performed better at high plant densities and seemed to better withstand the effects of strong competition.

Decreased size of the mature plant at close spacings can be extreme. When spaced at six plants per square meter, subterranean clover averaged 34 grams per plant, but when grown at a density of 1,500 plants per square meter, each mature plant weighed only .6 grams. The latter spacing was the one at which a maximum yield was obtained. Seed produced by broad beans at 11 plants per square meter weighed 29.7 grams per plant. Maximum yield was at 66 plants per square meter, but each plant only produced 9.3 grams (7).

Loomis and Williams (10) indicate that perhaps the major limitation to attaining high yields with annual crops is the length of time from seeding until the plant leaf area is maximum. This period of low LAI can best be shortened by increasing the seeding rate per unit area. Traditionally this has been done by increasing the plant density within the crop row. Many trials have been reported and most demonstrated that increasing the seeding rate within wide rows was of limited effectiveness. When row spacing was decreased, significantly higher yields were obtained. For example, Mack and Frazier (12) reported increasing snap bean population from 6 to 15 plants per foot only increased yield from 2.9 to 3.3 tons per acre. The increased yield did not produce an economic return when added seed and picking costs were calculated.

On the other hand, three years of trials (11) showed that if row spacing was decreased from 3 feet to 1 foot with a constant stand within the row, 'Processor' yields were increased 35 percent, 'OSU 412' 55 percent, and 'Top Crop' 65 percent. A summary of seven years data showed that yield increases of bush beans averaged 44 percent when row spacing was decreased from 36 to 12 inches with variations from 11 to 83 percent. When row spacing was reduced to 24 inches from 36 inches, the average yield increase was 24 percent with a range of 1 to 59 percent.

New York trials (1) showed a definite yield increase when snap beans were grown in 9 or 18 instead of 36-inch rows. The seeding rate of 30 seeds per square yard was constant, but yields were increased 20 percent on the average at the closer spacing. Production was at a higher level with 48 plants per square yard, but yield was 19 percent higher when planted in 9 instead of 36-inch rows. Dry bean yields were increased, but to a lesser degree, by the same row spacing comparisons.

Southern pea yields were also increased by closer row spacing (20). Highest production was from 18-inch rows, which yielded

37 percent more than 42-inch rows. Intermediate row spacings of 36, 30, and 24 inches produced increases of 6, 18, and 24 percent, respectively. Soybean yield was highest from 24-inch rows, but 8, 16, and 32-inch rows produced more than 40-inch rows in Illinois trials (19).

Bleasdale (3) reported results with peas, beets, and spinach which illustrated how the pattern of plant arrangement affected total yield. Pea yields were higher if the optimum plant density were distributed evenly to permit maximum growth before leaf shading from adjacent plants occurred. Spinach in 8-inch rows yielded more dry matter than when planted in 16-inch rows. By observing how beet leaves were arranged, it was evident that 12-inch rows more quickly and uniformly covered the unit area than did 24-inch rows. As plants approached maturity in 12-inch rows, there was never less than a cover of one leaf and on an average no leaf was completely covered by another layer. At 24 inches, some surface was not covered by leaves and many leaves were entirely shaded by others.

The same author's work (4) indicated that beets, carrots, onions, and potatoes will produce maximum yields if uniformly spaced in a relatively solid stand. He proposed that except for plants sown at a very low density, the curve for maximum weight production at higher densities merges into a single curve as time from seeding is graphed. He concluded that the evidence suggests that the total yield of competing crop systems is not limited by deficiencies in the amount of canopy except at very low densities. The weight of the plant in an enforced sharing of supplies of water, nutrients, and light which are not variables was influenced by density of planting.

Donald (7) indicated that various crops, especially pasture species, tended to produce a constant dry matter yield over a wide range of high densities. Individual plant size varied greatly with smaller plants at closer spacings. Bleasdale (5) also observed that as a result of changing plant density the ratio between the relative changes in the weight of the whole plant and the relative changes in the weight of the plant part was constant.

This is a very important factor because it means that as the total yield approaches the relatively constant value and if the yield of the economically valuable portion of the plant remains a constant proportion even though individual plant weights differ, then economic returns will be expected over a wide range of plant stand. This density variable could be utilized to produce individuals of a certain desired size, especially with root crops where size is of importance. For example, closer spacing would produce small size carrots for a processor's whole pack. Larger carrots could be produced by planting at wider spacings and would be suited for dicing or for soup ingredients. These uses could be considered with relatively constant yield high enough for profitable farming.

Unpublished data from New Zealand trials (22) showed that maximum total yields of several vegetables were produced by plant spacings much closer than those used in present farming practices. For example, the following crops and optimum spacings were included: pole beans, 36 x 10 inches; cabbage, 24 x 10 inches; carrots, 12 x 4 inches; lettuce, 12 x 12 inches. It was shown that spacing had a profound effect on size and grade of the saleable product but a small effect on the total saleable yield.

On a commercial scale we can probably do nothing about the amount of light that a given area will receive; however, plants might be arranged so that their leaves intercept it more effectively. Vegetable plants do not necessarily function best when grown in rows, but it is a method that has developed through the years for most economical planting, cultivation, pest control, and harvesting of these crops. Interest in bed culture has increased with the advent of herbicides which will permit the production of some crops without cultivation (3). Engineers are also approaching the problem of precision seeding and mechanical harvest of various crops from a solid stand of plants.

MATERIALS AND METHODS

Plot Layout

The experimental plots were located at the Oregon State University Vegetable Research Farm at Corvallis. The soil type is Chehalis silt loam and is comparable to the soils on which many beans in the Willamette Valley are grown. The trial consisted of eight spacing treatments with five replications arranged in a randomized block design. Spacings were 4 x 4, 5 x 5, 6 x 6, 7 x 7, 8 x 8, and 9 x 9 inches in square arrangements. Plant arrangement was compared at spacings of 6 x 6, 24 x 1-1/2, and 36 x 1 inches. Two bush snap bean cultivars were in sub plots. 'Tendercrop' is a standard commercial variety grown for freezing. 'OSU 949' is a dwarf 'Blue Lake' selection from the breeding program at Oregon State University and comes from a series of backcrosses to 'Blue Lake' pole beans. Plots were 10 feet long and approximately 6 feet wide, depending on the spacing. The number of rows varied from 18 at 4 inches to 8 at the 9-inch spacing. Five rows per plot were used for the 24 and 36-inch row spacings.

Planting Technique

Plots were planted on July 6 and 7, 1966. Seed was placed in a furrow with a planting board that had depressions drilled in it at the appropriate spacings. Two seeds were placed in each depression, planted in a furrow, and covered with soil. Shortly after emergence the plots were thinned to one plant at each desired location.

Estimated seeding rates for the spacings are in Table 1. These figures are based on 90 percent survival and a seed size of 1,400 per pound for 'Tendercrop' and 1,700 per pound for 'OSU 949.'

General Culture

Approximately 800 pounds per acre 8-24-8 fertilizer was broadcast and disced in before planting and no additional fertilizer was added. Weed control, irrigation, and insect control were accomplished to provide good growing conditions during the experiment. No cultivation of the crop was done throughout the growing season. The weeds that emerged were controlled by early season hand weeding.

Harvest

Observations on general growth were made during the season and harvest was on September 13 and 14, 1966. A single row was harvested from the center of each plot to avoid border effect; the plants from each end of the row were discarded. Gross plant weights were obtained and the pods were hand stripped from the plant to simulate machine harvest. Weights were recorded and the pods were bulked by

Table 1. Area per Plant, Plants per Acre, and Estimated Seeding Rates for Various Spacings.

Spacing (inches)	Square inches per plant	Plants per acre	Pounds seed per acre	
			Tendercrop	OSU 949
4 x 4	16	392,040	308	254
5 x 5	25	250,905	197	163
6 x 6	36	174,240	136	112
7 x 7	49	128,015	100	82
8 x 8	64	98,010	77	64
9 x 9	81	77,440	61	51
36 x 1	36	174,240	136	112
24 x 1-1/2	36	174,240	136	112
6 x 6	36	174,240	136	112

treatment for sieve size determination. Sieve size grades were obtained from a mechanical bean grader at the pilot plant of the Department of Food Science and Technology.

A single plant was chosen from each treatment in a single replication to represent a typical plant for determination of leaf weight and area. Leaves were stripped from the plant, spread on a grid, and photographed. Uniform enlargements were made from which the leaf surface area was measured with a planimeter.

RESULTS

Yield and Sieve Size Distribution of Snap Beans

Yield and sieve sizes for plants in a square arrangement are shown in Table 2. Table 3 presents yield and sieve size data for arrangement wherein all plants had 36 square inches each.

'Tendercrop.' Maximum yield of 10.1 tons per acre was produced at the 7 x 7 inch spacing. Non-significant, but lower yields were obtained at the 5 x 5 and 6 x 6 inch spacings. When crowded more closely together or given wider spacings, bean yields were reduced significantly.

The sieve size distribution indicated that maturity was delayed by close spacing. There was a fairly consistent general trend toward larger beans as indicated by the 60 percent for sieve size 4 and smaller at the 4 x 4 inch spacing and 31 percent at the 9 x 9 inch spacing.

The plant arrangement data indicated that there was no significant difference in the yield of 'Tendercrop' whether the plants were in rows or on a 6 x 6 inch square arrangement. The sieve size, however, indicated that pods were more mature in the 36 or 24-inch rows compared with the square spacing arrangement.

Table 2. Effect of Spacing on Yield and Sieve Size Distribution of Snap Beans.

Spacing (inches)	Tendercrop Yield (T/A)	Tendercrop Sieve size (% 4 and smaller)	OSU 949 Yield (T/A)	OSU 949 Sieve size (% 4 and smaller)
4 x 4	8. 3	60	13. 0	38
5 x 5	9. 2	43	13. 3	31
6 x 6	8. 9	41	12. 6	32
7 x 7	10. 1	32	10. 7	30
8 x 8	8. 2	35	9. 7	29
9 x 9	6. 6	31	8. 5	25
Avg.	8. 5	40	11. 3	31
LSD . 05	1. 4		1. 4	
. 01	1. 9		1. 9	

Table 3. Effect of Plant Arrangement on Yield and Sieve Size Distribution of Snap Beans.

Spacing (inches)	Tendercrop Yield (T/A)	Tendercrop Sieve size (% 4 and smaller)	OSU 949 Yield (T/A)	OSU 949 Sieve size (% 4 and smaller)
36 x 1	9. 2	25	9. 4	28
24 x 1-1/2	9. 4	26	9. 6	29
6 x 6	8. 9	41	12. 6	32
Avg.	9. 2	31	10. 5	30
LSD . 05	NS		1. 0	
. 01	NS		1. 5	

'OSU 949.' At comparable spacings 'OSU 949' produced a significantly higher yield than 'Tendercrop' with the exception of the plantings in 36 or 24-inch rows. The three closest spacings, 4 x 4, 5 x 5, and 6 x 6 inches, were not significantly different, but had the highest yields in the trial. Yields dropped significantly as plants were spaced farther apart.

The sieve size variation was not as extreme as with 'Tendercrop,' but the wider spacing produced larger pods with the highest percentage of small sieve size beans at the 4 x 4 inch spacing.

When grown in rows, 'OSU 949' produced approximately the same yield as did 'Tendercrop.' The 6 x 6 inch spacing produced a significantly higher yield with a higher percentage of small beans.

Yield Adjustment for Sieve Size

Processors pay growers on the basis of a sieve size grade. Unpublished information indicates that for each 10 percent change in sieve size the yield should be adjusted by about .5 tons per acre. Table 4 shows the plot yields on a basis of adjusting to a 50 percent sieve size 4 and smaller. If the plot grade had a sieve size figure of more than 50 percent, the yield was adjusted upward. For a sieve size grade less than 50 percent, the adjusted yield was higher than that obtained in the trial.

In general, this manipulation lowered the yield of the wider

Table 4. Snap Bean Yields Adjusted to 50 percent Sieve Size 4 and Smaller.

Spacing (inches)	Tendercrop (T/A)	OSU 949 (T/A)	Avg. (T/A)
4 x 4	8.9	12.2	10.5
5 x 5	8.8	12.3	10.5
6 x 6	8.4	11.5	10.0
7 x 7	9.3	9.7	9.5
8 x 8	7.4	8.8	8.1
9 x 9	5.6	7.3	6.4
36 x 1	8.0	8.3	8.2
24 x 1-1/2	8.2	8.6	8.4
6 x 6	8.4	11.5	10.0
Avg.	8.1	9.8	

spaced plantings because of the smaller percentage of small sieve size beans. If the data from both cultivars were averaged, there was a consistent trend toward higher production at closer spacings. In addition, the uniform spacing of 6 x 6 inches produced a higher yield than when the beans were grown in either 36 or 24-inch rows.

Plant Size and Plant-Pod Ratio

When in a square arrangement, 'Tendercrop' and 'OSU 949' plants were much smaller at the closer plant spacings (Table 5). The overall plant size for 'Tendercrop' was larger than for 'OSU 949' with the average weight of 'Tendercrop' being 163.2 grams and for 'OSU 949,' 142.4 grams per plant.

Plants grown at a 6 x 6 inch spacing were larger than when the same space was allotted in a 24 or 36-inch row. The smallest plants were those which were grown one inch apart in a 36-inch row.

The average plant-pod ratio of 'Tendercrop' was 1.83 compared with 1.02 for 'OSU 949.' There seemed to be little if any consistent trend at the different plant spacings or arrangements, but the 'Tendercrop' plants grown in 24 or 36-inch rows had a much lower plant-pod ratio than when grown at any of the other spacings.

Plant Leaf Area

Table 6 shows the leaf area index (LAI) at harvest of a "typical"

Table 5. Effect of Arrangement and Spacing on Plant Size and Plant-Pod Ratio.

Spacing (inches)	Plant size (grams per plant)		Plant-pod ratio	
	Tendercrop	OSU 949	Tendercrop	OSU 949
4 x 4	58.9	67.4	2.31	.88
5 x 5	117.0	97.6	1.95	.99
6 x 6	154.1	137.8	2.16	1.11
7 x 7	215.1	169.3	1.89	1.07
8 x 8	227.4	194.7	1.94	1.06
9 x 9	248.9	223.3	2.00	1.02
36 x 1	136.2	116.2	1.14	1.01
24 x 1-1/2	148.3	133.0	1.30	.98
6 x 6	154.1	137.8	2.16	1.11
Avg.	163.2	142.4	1.84	1.02

Table 6. Effect of Arrangement and Spacing on Leaf Area Index and Soil Coverage.

Spacing (inches)	Leaf area index at harvest		Days from planting to complete soil coverage
	Tendercrop	OSU 949	
4 x 4	9. 9	8. 2	34
5 x 5	10. 9	7. 3	35
6 x 6	8. 2	5. 3	37
7 x 7	6. 4	5. 3	40
8 x 8	7. 4	4. 7	43
9 x 9	9. 1	4. 8	47
36 x 1	3. 8	3. 6	59
24 x 1-1/2	4. 4	3. 7	56
6 x 6	8. 2	5. 3	37
Avg.	7. 5	5. 4	

plant which was chosen from each treatment, but was not replicated. Although individual plants were much larger when grown at wider spacings, the closer plantings had the highest LAI. 'OSU 949' LAI values were lower than for 'Tendercrop.' When grown in 24 or 36-inch rows, the LAI was lower than for any of the square arrangements.

The LAI of 'OSU 949' plants at the 6 x 6 inch spacing was approximately 50 percent higher than when grown in 24 and 36-inch rows, respectively, and yields were approximately 30 percent higher. Other LAI values were generally related to the yield of 'OSU 949' with the lowest values at the wider spacings where yields were also lower.

'Tendercrop' did not respond as did 'OSU 949' in that the LAI of the highest yielding 7 x 7 inch plot was 6.4. This figure was not as high as that of other spacings which yielded less. When 'Tendercrop' was grown at 36 square inches per plant, but in different arrangements, LAI values differed widely, but pod yield was not significantly different.

Soil Surface Coverage

Although the plant growth of 'Tendercrop' was more upright and the plants were larger than 'OSU 949,' the two cultivars produced approximately the same ground coverage at a given interval from planting. The 'OSU 949' growth habit was more prostrate and the foliage tended to "sprawl" close to the ground. The plants in the 24 and 36-inch rows required the longest interval to achieve soil coverage.

DISCUSSION

Production of bush snap beans can be increased by manipulating the plant population density and planting arrangement. Based on the results of this trial, one cannot generalize and select an optimum spacing arrangement at which to plant all bush bean cultivars. The distinct difference between the performance of 'OSU 949' compared with that of 'Tendercrop' with its larger, more upright plant was of particular interest. Maximum yields of 13.3 tons per acre from 'OSU 949' were obtained from the 5 x 5 inch spacing (25 square inches), but 'Tendercrop' produced its maximum yield of 10.1 tons per acre at 7 x 7 inches, almost twice the area per plant. 'Tendercrop' did not seem to be able to withstand the close spacings and intense competition as well as did 'OSU 949.'

Neither did 'Tendercrop' seem to be physiologically as efficient as 'OSU 949' because at all spacings the yield was less and yet the plant had a higher leaf area index (LAI). In all but the 4 x 4 inch spacing 'Tendercrop' plants were larger. The 'Tendercrop' plants were drastically reduced in size under crowded conditions with weights of only 58.9 grams per plant at 4 x 4 inches compared with 215.1 grams at the 7 x 7 inch spacing where maximum yields were obtained. 'OSU 949' plants were not as large as 'Tendercrop' at the 5 x 5 inch spacing where maximum yields were obtained, but when crowded more closely together were not reduced to the extent of 'Tendercrop.'

'OSU 949' consistently yielded more than 'Tendercrop' at comparative spacings. Photographs of the two cultivars (Figures 1 and 2) show the pronounced branching habit of 'OSU 949' compared to the few branches produced by 'Tendercrop.' Hodgson and Blackman (9) found that at increased densities, Vicia faba plants had fewer pods per plant, but acre seed production was governed solely by the total number of mature pods formed. Thus, as flowers were borne on the ends of branches, yield was increased in relation to the number of inflorescences that were formed. Perhaps their findings that increased density depressed the blooms on lower nodes might apply to the snap bean cultivars tested. 'OSU 949,' with more branches per plant, might have had more upper nodes for blossom and pod formation than did 'Tendercrop.'

When the plant-to-pod ratio was calculated, this difference in efficiency was very pronounced. The overall range from 'OSU 949' was from .88 at the 4 x 4 inch spacing to 1.11 at the 6 x 6 inch spacing with other spacings intermediate for an average ratio of 1.02. In other words, for each 102 grams of plant weight, 100 grams of pods were produced. The ratio for 'Tendercrop' was markedly higher (less efficient) with a range of 2.31 to 1.14 and an average of 1.84.

The two cultivars were harvested within the same two-day

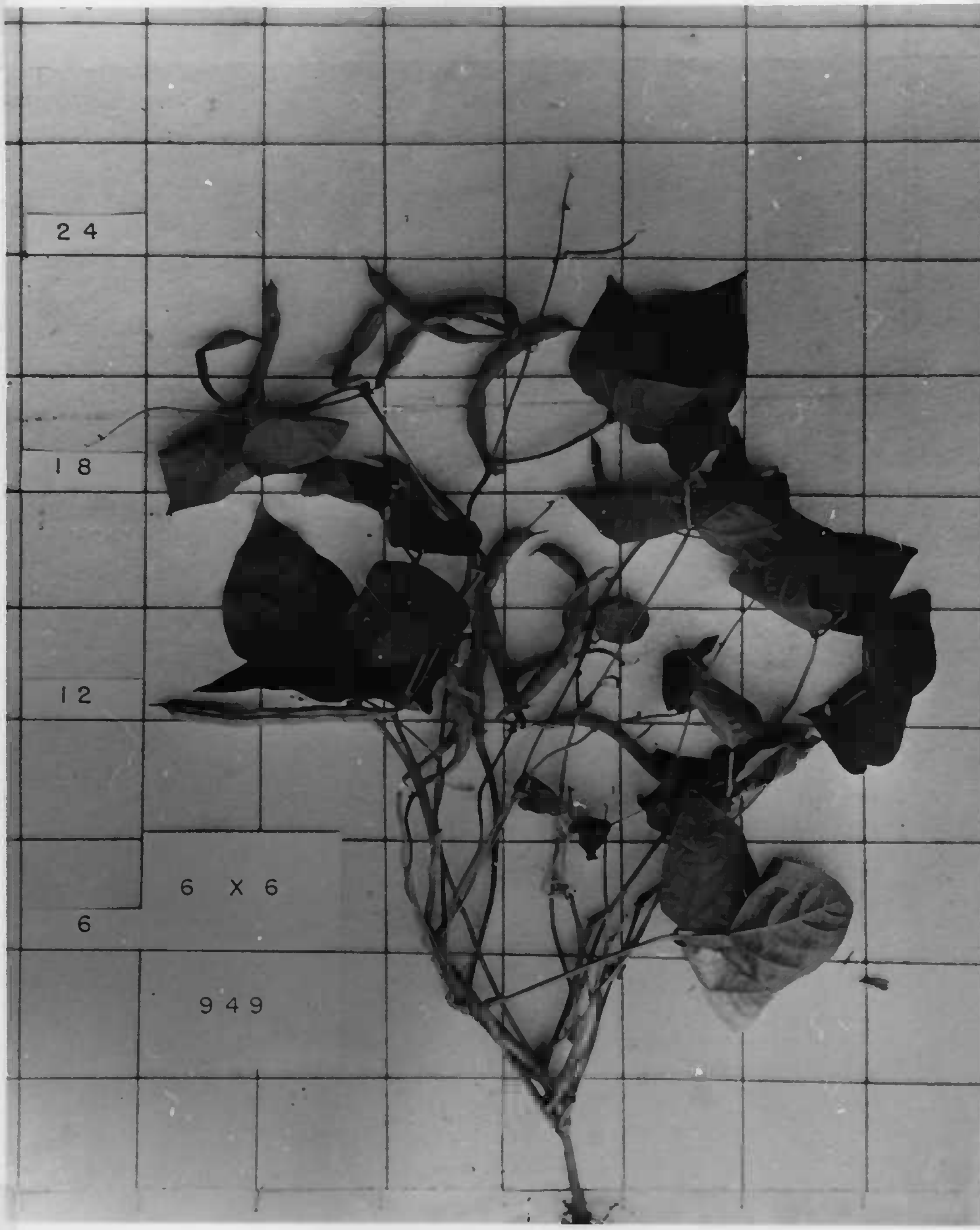

Figure 1. Growth habit of 'OSU 949' from 6 x 6 inch plot. Grid is 3 x 3 inches.

Figure 2. Growth habit of 'Tendercrop' from 6 x 6 inch plot.
Grid is 3 x 3 inches.

period. The data presented in Table 2 indicate that there was a difference in maturity as reflected in the sieve size distribution. 'Tendercrop' consistently had the highest percent of pods sieve size 4 and smaller, with the average for all spacings of 40 percent. 'OSU 949' was more mature with only 30 percent in that category. The fact that the beans were more mature and yield was higher would tend to make the plant-pod ratio lower. Future trials should probably include time of harvest variables for determining optimum harvest dates.

There was a definite increase in LAI as plants were spaced closer together in a square arrangement. This increase may have been responsible for the general trend toward higher yields at the closer spacings. Davidson and Donald (6) reported that production of dry matter was rather well correlated with the LAI in a subterranean clover sward with a value of 4 to 5 associated with maximum yield. Their work showed that even if leaves were exposed to filtered light that the lower layers contributed to dry matter production.

'Tendercrop' plants, even though their plant size and LAI were larger, produced less yield than 'OSU 949.' Perhaps this relates to the efficiency of the plant wherein the plant-pod ratio was generally higher than for 'OSU 949.'

Lowest LAI values were from plants grown in 36 or 24-inch rows. Competition under these conditions of 1 or 1-1/2 inch spacing, respectively, could be expected to occur much earlier in the season than under conditions of 4 or more inches of space between plants. When 36 square inches were allotted each plant, they had a much higher LAI if grown in a 6-inch square pattern, rather than 24 or 36-inch rows.

One might suppose that in spacing plants closer together there would be a greater incidence of diseases such as white mold or other fungus diseases attacking the stem or pod. The plants were very upright at the closer spacings and perhaps the crowded plants held the pods higher off the ground and promoted ventilation early in the life of the plant. No data were reported on this aspect of the trials because there was no disease problem in any plot.

For this preliminary experiment there were many variables that were either not measured or tested that could have had an influence on the results. For example, the effects of different fertilizer levels or methods of application were not evaluated. The cultivar difference was explored only to a limited degree, but based on these results one might conjecture that each cultivar might have its own optimum spacing. Although the differences in sieve sizes were minor until very crowded conditions were imposed, it would be very useful to know how the spacing variables affect the bearing habit including the percent set of blooms, the nodes where pods are borne, and the height at which the crop is located on the plant.

SUMMARY

A field experiment was conducted to determine the effects of plant spacing and arrangement on yield of two cultivars of bush snap beans. They were 'Tendercrop,' a standard commercial bush bean for processing in the Willamette Valley, and 'OSU 949,' a dwarf 'Blue Lake' derivative developed at Oregon State University.

Plants were grown one inch apart in 36-inch rows and 1-1/2 inches apart in 24-inch rows to compare with square arrangements of 4 x 4, 5 x 5, 6 x 6, 7 x 7, 8 x 8, and 9 x 9 inches. Plant populations varied from 77,000 plants per acre at a 9 x 9 inch spacing to 392,000 plants per acre at a 4 x 4 inch spacing. 'OSU 949' seeding rate varied from approximately 50 pounds per acre to 255 pounds per acre. 'Tendercrop,' with larger seeds, required 60 to 310 pounds per acre.

Bean yields were highest when plants were grown at uniform spacings. 'OSU 949' produced 34 percent more when grown in a square arrangement (6 x 6 inches) compared with the same number of plants in 36-inch rows and 32 percent more than in 24-inch rows. Crowding the plants to a 5 or 4 inch square spacing increased yields even more.

Highest yield for 'Tendercrop' was at a 7 x 7 inch spacing, indicating less tolerance to crowding. When row culture was compared to a 6 inch square planting, there was no significant difference in yield. At a given spacing, 'Tendercrop' produced less yield than did 'OSU 949.'

Both cultivars were harvested at the same time and 'OSU 949' was more mature as indicated by sieve size data. When yields were corrected to compensate for this variation, the above basic comparisons were still valid. As either cultivar was more widely spaced, yield was reduced, and the row method of culture, on the average, produced lower yields.

Smaller pods were produced at the closer spacings. When grown in 24 or 36-inch rows, maturity was hastened and the smallest percent sieve size 4 and under was obtained.

Even though individual plants were larger, 'Tendercrop' yielded less than 'OSU 949.' When grown uniformly spaced instead of in 36 or 24-inch rows, plants weighed more. Plant-pod ratios indicated that 'OSU 949' with an average of 1.02 was more efficient than 'Tendercrop' with an average ratio of 1.84.

When leaf surface was calculated, the difference in efficiency was also evident. 'Tendercrop' plants developed an average LAI value of 7.1 and yielded less than 'OSU 949' with a value of 5.4. The LAI of 'OSU 949' tended to be higher at closer spacings and these plots also produced the higher yields. The same trend, though not as clearly evident, was indicated for 'Tendercrop.' Plants grown in rows had a considerably lower LAI than when spaced 6 x 6 inches.

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APPENDIX

Appendix Table 1. Complete Plot Yield Compared with 10-Plant Subplot Yield of Snap Beans.

Spacing (inches)	Tendercrop			OSU 949		
	10-Plant subplot		Complete plot yield (T/A)	10-Plant subplot		Complete plot yield (T/A)
	pods/plant (grams)	acre yield (tons)		pods/plant (grams)	acre yield (tons)	
4 x 4	18	7.7	8.3	36	15.5	13.0
5 x 5	40	10.9	9.2	49	13.5	13.3
6 x 6	49	9.3	8.9	65	12.5	12.6
7 x 7	74	10.9	10.1	82	11.5	10.7
8 x 8	77	8.3	8.2	95	10.2	9.7
9 x 9	83	7.0	6.6	110	9.4	8.5
36 x 1	64	12.2	9.2	58	11.1	9.4
24 x 1-1/2	65	12.4	9.4	67	12.9	9.6
6 x 6	49	9.3	8.9	65	12.5	12.6

Appendix Table 2. Effect of Plant Spacing and Arrangement on Sieve Size Distribution of Snap Beans.

Spacing (inches)	Percent in sieve size									
	1-3		4		5		6		7	
	Tender-crop	OSU 949	Tender-crop	OSU 949	Tender-crop	OSU 949	Tender-crop	OSU 949	Tender-crop	OSU 949
4 x 4	33.3	20.4	26.3	18.0	26.3	24.7	8.8	35.9	5.3	1.2
5 x 5	23.4	17.2	19.8	13.9	34.6	25.4	18.5	36.9	3.7	6.6
6 x 6	22.0	16.3	18.7	15.6	25.3	21.5	26.4	32.4	7.6	14.2
7 x 7	17.7	17.5	14.6	12.4	23.1	22.6	28.5	32.1	16.1	15.4
8 x 8	19.5	17.1	15.0	12.3	20.4	19.2	30.1	32.2	15.0	16.6
9 x 9	18.0	13.4	13.5	11.9	23.4	18.7	31.5	35.1	13.6	20.9
36 x 1	11.4	14.4	13.4	13.8	24.8	21.3	36.2	37.8	14.2	12.7
24 x 1-1/2	14.4	14.7	11.2	14.7	25.6	27.6	30.0	31.2	18.8	11.8
6 x 6	22.0	16.3	18.7	15.6	25.3	21.5	26.4	32.4	7.6	14.2

Appendix Figure 1. General view of plots. July 29, 1966. Thinning to single plant.

Appendix Figure 2. Planting board with holes to insure uniform stand. Adjacent to row with one inch plant spacing.