Tobacco Science, 1982, 26-2, p. 4-8, ISSN. 0082-4523.pdf

PHYTOTRON STUDIES ON TOBACCO SEEDLING PRODUCTION
I. EFFECT OF PLANT SPACING ON GROWTH[1]

By MOHAN GAWANDE and W. H. JOHNSON[2]

Six place spacings of 2.5 x 2.5, 3.8 x 3.8, 5 x 5, 7.6 x 7.6, 5 x 10 and 5 x 15 cm^2 were tested for Asgrow pellets under day/night temperatures of 26/22 C. Plants were grown in metal containers using a subirrigation system. Plants were harvested about six weeks after seeding and measured for several plant parameters. Results showed that most of the plant parameter values increased asymptotically with increasing plant spacings. Non-linear (negative exponential) regression equations were fitted. Plant parameters vs. spacing curves were smoother when the plots were made against the larger side of the spacing grid as compared to the plots against area per plant. Stem length, plant height, and stem weight were not influenced significantly by plant spacing. Plants at closer spacings tended to be more variable in size as compared to those at wider spacings, although the variability was not statistically significant.

INTRODUCTION

Transplantability of tobacco seedlings depends to a great extent upon size and "style" of transplants. The "style" is a function of several plant parameters such as stem diameter and length, leaf size, plant height, leaf angle and weight of different plant components. Transplants having an upright growth habit and a sturdy stem of about 5-10 cm in height are, by farm experience most suitable for mechanical transplanting. Uniformity in such transplant characteristics probably enhances the effectiveness of mechanical transplanting with respect to field survival and early growth and may also positively affect the uniformity of mature plants.

The effect of plant spacing on post-transplant growth and yield of tobacco has been studied extensively, but relatively little has been reported on the effect of plant spacing on pre-transplant growth. Hay and Westmuller (5) recommended attaining a population of 538-646 plants/m^2 (50-60 plants/ft^2) by thinning a more densely populated seedbed. Walker (9) found that transplant size, early growth and survival were enhanced by decreasing seeding density from 0.1695 g/m^2 of seed to 0.1017 g/m^2 (approximately 2090 seed/m^2 to 1255 seed/m^2). Splinter and Suggs (8) concluded that plant losses after transplanting for small, stocky plants (5 cm height, 0.6 cm stem diameter) were three to six times as great as for medium (10 cm height, .95 cm stem diameter) or large (15 cm height, 1.27 cm stem diameter), stocky plants. Tall, slim transplants (15 cm height, 0.6 cm stem diameter) suffered two to three times as many losses after transplanting as the large, stocky transplants. The authors also reported that differences in size within type, i.e., stocky or slim, persisted until harvest, and although smaller plants matured later, yields were essentially the same for different sizes within type.

Field observations of seedlings grown at different seed spacings (6) suggest that within- and between-row spacings of seed

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[1] Paper Number 5935 of the Journal Series of the North Carolina Agricultural Research Service, Raleigh, N.C. The use of trade names in this publication does not imply endorsement by the North Carolina Agricultural Research Service of the products named, nor criticism of similar ones not mentioned.

[2] Graduate Student, Operations Research and Professor, Dept. of Biological and Agricultural Engineering, N.C. State University, Raleigh, NC 27650.

Contribution received April 4, 1979. Tob. Sci. XXVI: 4-8, 1982.

may relate to both uniformity and "style" of plant development. A comprehensive investigation of the influences of environmental and seed factors on growth and uniformity of tobacco seedlings was undertaken via a phytotron study in the Southeastern Plant Environment Laboratories at North Carolina State University, Raleigh, NC (4). The present paper concerns a seed spacing experiment in this study.

Table 1. Plant spacings used in spacing study.

SPACING			Area Per Plant cm^2	No. of Plants per m^2
in x in	cm x cm	Text Reference		
1 x 1	2.54 x 2.54	2.5 x 2.5	6.45	1550.0
1.5 x 1.5	3.81 x 3.81	3.8 x 3.8	14.52	688.9
2 x 2	5.08 x 5.08	5 x 5	25.81	387.5
2 x 4	5.08 x 10.16	5 x 10	51.61	193.7
3 x 3	7.62 x 7.62	7.6 x 7.6	58.06	172.2
2 x 6	5.08 x 15.24	5 x 15	77.42	129.2

MATERIALS AND METHOD

Based on typical tobacco seedbed populations in North Carolina (320 to 450 plants/m^2), six plant spacings were chosen for this study (**Table 1**). Seeds were planted in rectangular grids and three different rectangularities were obtained by changing side ratios. The phytotron environment (3) consisted of a 9-hour day with both fluorescent and incandescent light and a day/night temperature regime of 26/22 C. A 1974 lot of flue-cured tobacco cultivar Speight G-28 was sized to 421-500 μ using an ATM Sonic Sifter (Fisher Scientific Co.) equipped with metric sieves, and pelletted with Lite Coat II, by Asgrow Seed Co. to about 1.5 mm diameter. These pellets split almost immediately upon contact with water.

A balanced incomplete block design with 5 replications of 6 treatments with 2 treatments per block was used **(Figure 1)**. Thus, a total of 15 blocks were required. A border row of plants was provided for each spacing to reduce border effect on inside harvestable plants for sampling.

Plants were grown in square, galvanized sheet metal containers 12.7 cm high, 45.7 cm x 45.7 cm in area, placed on standard phytotron carts, 90 cm high. Containers were filled with a 1:1 (volume to volume) mixture of peatlite and fine sand with a 1.3 cm layer of coarse sand at the bottom. The layer of coarse sand distributed irrigation water evenly in the bottom layer of the mix. A subirrigation system was used in this study. Tap water in the first two weeks and nutrient solution (3) in the later stages of growth was fed to the bottom sand layer on alternate days.

Two seeds were planted in each station of the spacing grid. When plants were about 2 cm in diameter, they were thinned or transplanted, as required, to obtain one plant per station. Metal partitions separated spacings in a container. Sample plants were harvested six weeks after seeding at which time overall average height of plants was transplant size of about 15 cm. Nine plants were harvested for spacings of 2.5 x 2.5, 3.8 x 3.8, 5 x 5 and 5 x 10 cm^2. Eight and six plants were sampled for spacings of 7.6 x 7.6 and 5 x 15 cm^2, respectively. Plants were selected randomly for sampling within each treatment.

The following parameters were obtained on individual plants: angle between the plant axis and the 4th leaf from the base, excluding the cotyledons; length and width of the 4th leaf; area of the 4th leaf as measured with an automatic leaf area meter (Hayashi-Denko Co., Ltd., Tokyo, Japan); plant height (from cotyledonary node to top of plant canopy); stem length (from cotyledonary node to base of the apical bud); total leaf area; and dry weights of leaves, stems and roots. The 4th leaf was selected since it was the largest leaf for most plants at time of measurement

RESULTS AND DISCUSSION

Analyses of variance were carried out for each plant parameter (2). Block effect was found to be nested within replication effect and the balanced incomplete block design was successful in reducing error sum of squares, significantly increasing precision for all parameters except the 4th leaf angle. This result should aid design of future spacing studies where space available for each experimental block is limited. Another analysis of variance showed that position of plants within a block with respect to nearest edge of the container did not have a significant effect on various plant parameters at the 0.05 level. It was

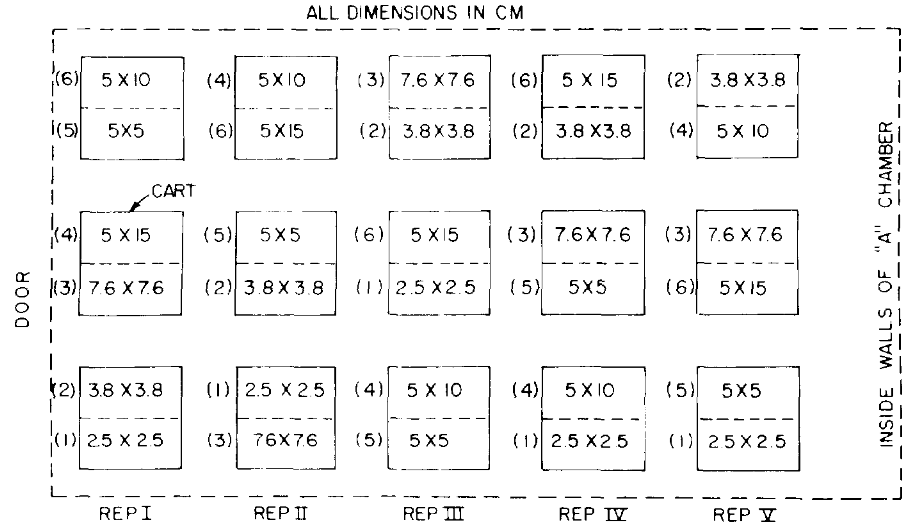

Figure 1. Balanced incomplete block design for spacing study. Treatment numbers inside parentheses are adopted from Cochran and Cox (1957) for six treatments, five replicates and a block size of two.

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concluded that the border effect was totally confined to the outermost row of plants.

Spacing, as measured by the larger side of spacing grid, significantly affected all plant parameters except plant height, stem length, and dry stem weight (see **Table 2**). Plots of stem length against spacing failed to show a consistent trend **(Figure 2)**; plots of plant height against spacing were similar. Other parameters obviously were affected by spacing **(Figure 2 to 5)**. Values for 4th leaf length, width and area and the number of leaves stabilized asymptotically with decreasing population **(Figure 2 and 3)**, whereas those for dry root weight, dry stem weight and total leaf area tended to increase linearly **(Figure 3 and 4)**.

In addition to the larger side of the spacing grid, the plant parameter values were plotted against area per plant. A significant feature of such plots was that a "dip" or local minimum was observed at the spacing of 7.6 x 7.6 cm^2. If the spacings are arranged in ascending order of X_i (larger side of spacing grid) the arrangement of 2.5 x 2.5, 3.8 x 3.8, 5 x 5, 7.6 x 7.6, 5 x 10, and 5 x 15 cm^2 is obtained; whereas, if the same spacings are arranged in ascending order of X_i' (area per plant), the sequence obtained is 2.5 x 2.5, 3.8 x 3.8, 5 x 5, 5 x 10, 7.6 x 7.6, and 5 x 15 cm^2. Thus, the spacings of 7.6 x 7.6 and 5 x 15 cm^2 exchange positions in the two orders. The "dip" noticed in plant parameters vs X_i' disappears completely if the plots are made against X_i. This feature is illustrated for dry leaf weight in **Figure 4** and **5**. The only exception to this behavior was exhibited by dry root weight, in which case the plots were smoother when drawn against grid area. It is suggested that inter-plant distance (as measured by X_i) is a more direct measure of inter-plant competition as compared to spacing grid area (X_i') in the first six weeks of growth.

An asymptotic relation was suggested by most of the spacing curves. The following model was proposed for non-linear regression analysis:

$$Y_i = B_0(1-\exp(-B_1 X_i)) + E_i$$

where

Y_i = value of plant parameter

X_i = plant spacing, ($= X_i$ or X'_i),

B_0, B_1 = non-linear regression coefficients, and

E_i = error term.

B_0 and B_1 were estimated by the Gauss-Newtom method of iterations (1), **Table 3**. B_0 refers to the value approached by a plant parameter (Y) as $X_i \rightarrow \infty$. If $B_0 \gg Y_{max}$, where Y_{max} is the maximum observed value, the plant parameter does not approach the asymptotic level in the given range of spacing. In such cases, a linear model was accepted, e.g., for dry leaf weight and dry root weight **(Table 3)**.

Variances for plant parameters measured at different plant spacings were found to be heterogeneous for all plant parameters except plant height, based on Bartlett's test (7). However,

Table 2. Adjusted means[1] and coefficients of variation (CV) for various parameters in spacing study.

		Spacing (cm x cm)					
Parameter		2.5 x 2.5	3.8 x 3.8	5.0 x 5.0	7.6 x 7.6	10.0 x 5.0	15.0 x 5.0
4th Leaf Angle (deg)	Mean	22.	41.	34.	32.	46.	45.
	CV	71.5	44.0	51.4	42.4	40.4	36.3
Height (cm)	Mean	14.5	15.6	14.8	15.2	16.7	15.6
	CV	31.5	28.5	32.7	31.8	28.7	24.7
4th Leaf Length (cm)	Mean	10.2	12.5	12.8	12.1	13.4	12.6
	CV	32.2	21.1	20.6	27.3	19.6	17.1
4th Leaf Width (cm)	Mean	5.0	6.5	7.4	7.6	7.9	8.8
	CV	35.1	25.5	19.0	25.0	18.9	17.8
Stem Length (cm)	Mean	5.2	5.9	4.9	3.8	5.4	4.5
	CV	39.1	38.2	40.9	48.4	28.7	34.7
Number of Leaves	Mean	5.7	6.6	7.3	8.1	8.6	8.5
	CV	16.4	25.4	17.7	13.3	14.7	13.9
4th Leaf Area	Mean	27.1	44.9	50.3	60.3	64.8	66.4
	CV	55.6	41.2	40.3	47.7	44.6	36.8
Total Leaf Area (cm^2)	Mean	82.7	149.5	204.3	260.9	293.1	346.1
	CV	51.1	62.4	55.1	47.3	35.5	34.8
Dry Leaf Weight (mg)	Mean	168	291	361	519	581	744
	CV	65.8	85.9	59.0	60.7	63.4	49.3
Dry Stem Weight (mg)	Mean	28	42	45	43	61	63
	CV	70.4	85.0	79.5	85.2	65.1	62.2
Dry Root Weight (mg)	Mean	19	24	41	49	46	69
	CV	84.6	83.9	93.2	77.1	67.8	76.9

[1] Mean adjusted for block effect by retrieving intra-block information in balanced incomplete block design.

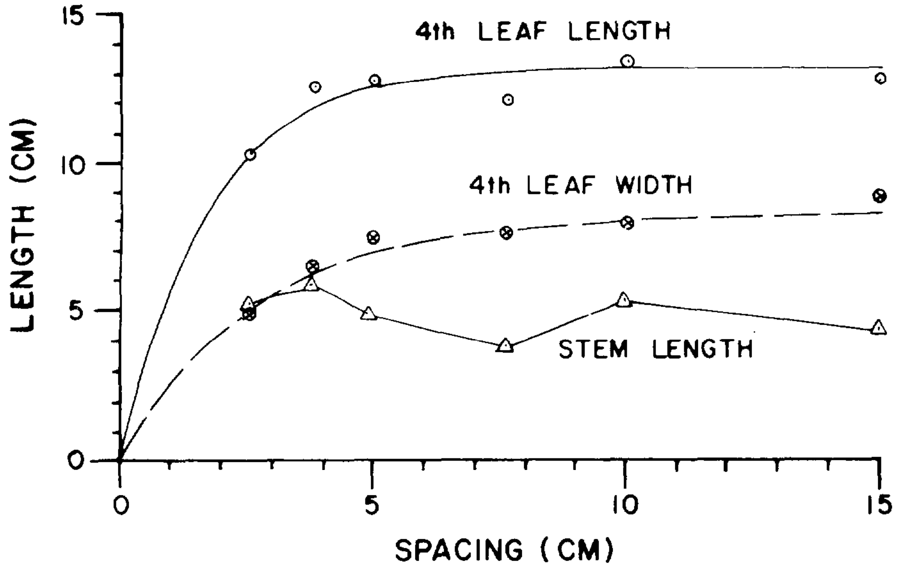

Figure 2. Plots of 4th leaf length, 4th leaf width and stem length against the larger side of the spacing grid. The points correspond to the adjusted, observed means and the curves for the first two parameters correspond to the regression equations in Table 3.

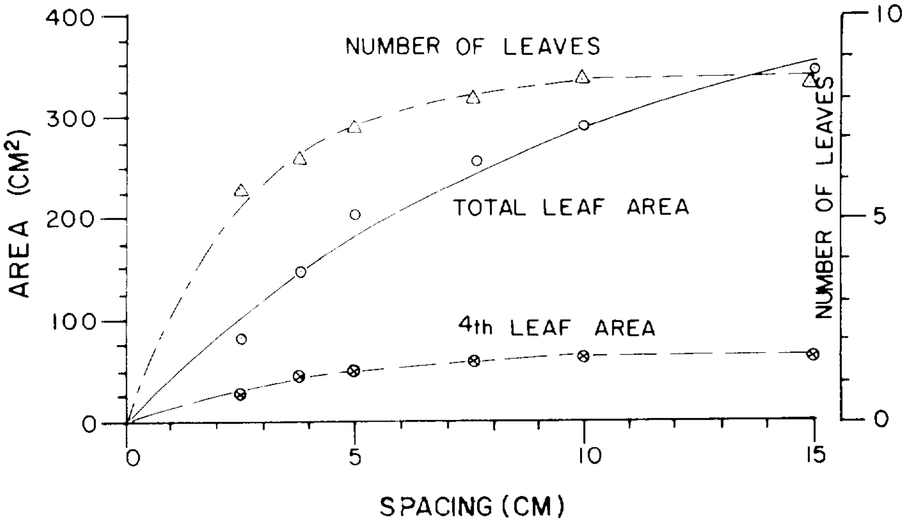

Figure 3. Plots of total leaf area, 4th leaf area and number of leaves against the larger side of the spacing grid. The points correspond to the adjusted, observed means and the curves correspond to the regression equations in Table 3.

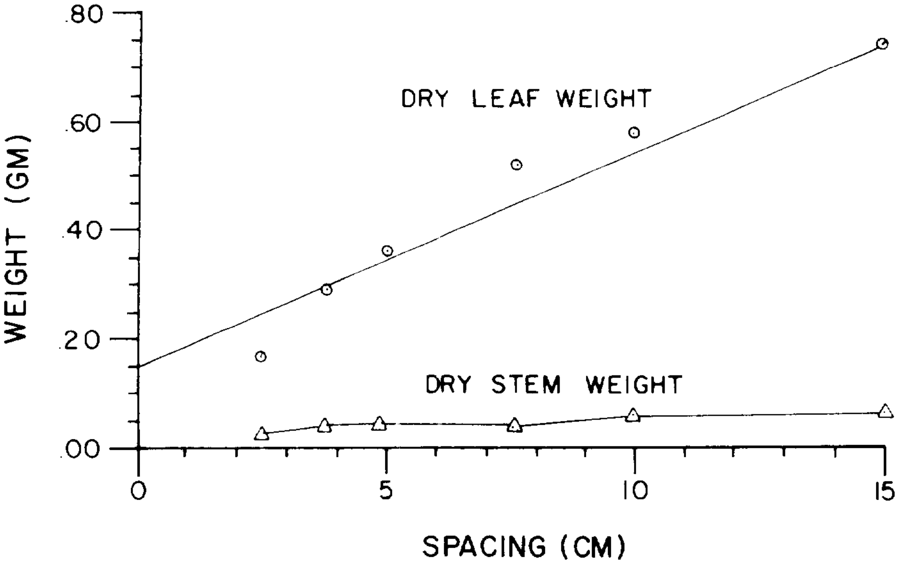

Figure 4. Plots of dry leaf weight and dry stem weight against the larger side of the spacing grid. The points correspond to the adjusted, observed means and the curve for dry leaf weight corresponds to the regression equation in Table 3.

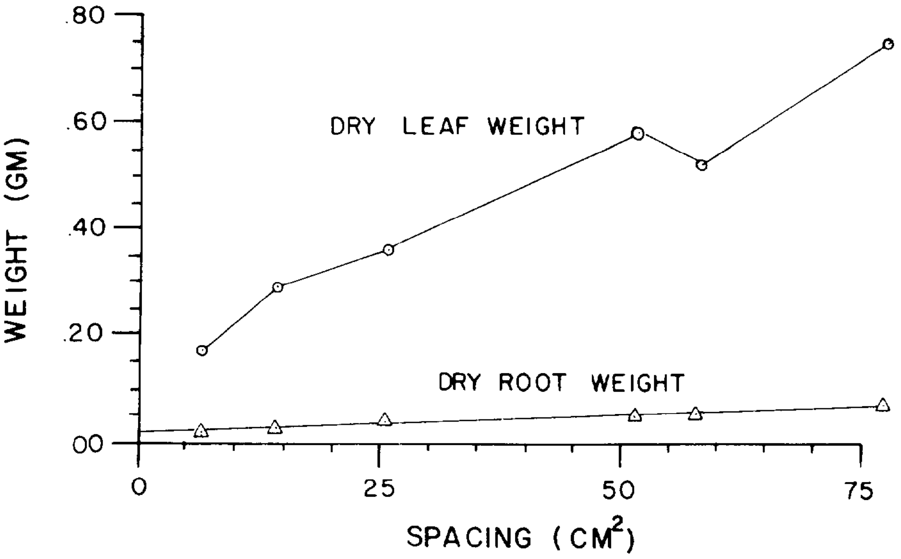

Figure 5. Plots of dry leaf weight and dry root weight against spacing grid area per plant. The points correspond to the adjusted means and the curve for dry root weight corresponds to the regression equation in Table 3.

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Table 3. Summary of regression analysis in spacing study with plant spacing as independent variable and plant parameter values as dependent variables.

PLANT PARAMETER Y_1	FITTED EQUATION $Y = B_o\,(1-\exp(-B_1 X))$	STANDARD ERROR OF B_o	B_1	R^2
4th Leaf Length, cm	$Y = 13.187\,(1-\exp(-0.6059\,X))$	0.4767	0.1177	0.980
4th Leaf Breadth, cm	$Y = 8.222\,(1-\exp(-0.3817\,X))$	0.2891	0.0477	0.985
Number of Leaves	$Y = 8.547\,(1-\exp(-0.4012\,X))$	0.2140	0.0371	0.992
4th Leaf Area, sq. cm	$Y = 71.624\,(1-\exp(-0.2270\,X))$	6.8523	0.0052	0.940
Total Leaf Area, sq. cm	$Y = 440.04\,(1-\exp(-0.1093\,X))$	74.546	0.0323	0.947
Dry Leaf Weight, $\times 10^3$ gm	$Y = 148.85 - 39.79\,X$	58.396	7.189	0.863
Dry Root Weight, $\times 10^3$ gm	$Y = 17.33 + 0.6106\,X'$	3.75	0.0861	0.933

X = Larger side of the spacing grid, cm

X' = Product of the two sides of the spacing grid, cm^2

coefficients of variation averaged over the various plant parameters increased with increasing plant density **(Table 2)**. This suggests, but without statistical significance, that plant variability increases with increase in plant density.

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