The Relationship Between Plant Stem Diameter and Total Leaf Area For Certain Plants Exhibiting Apical Dominance[1]

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The most generally accepted measure of plant growth is dry matter weight. However, this method requires the destructive sampling of a population of plants and does not lend itself to measurement of short term responses of the plant to changes in environment. Leaf area can be linearly correlated with dry matter weight under a given set of conditions and can be determined in a non-destructive manner. Since the plant derives its energy for growth by intercepting light, leaf area is a criterion which is essential for considerations of energy balance and has special significance for crops such as tobacco where the leaves are of economic importance.

Table 1. Regression Equations for Determining Leaf Area

Crop	Regression Equation	Std. Error S_e or Correlation Coefficient r	Source
Cabbage[a]	A = .772 LW		
Cocklebur	A = 0.69 LW	r^2 = .994	Eide 1964
Corn	A = 0.73 LW	——	McKee 1964
Corn[a]	A = 0.71 LW	r^2 = .991	Eide 1964
Cotton	A = 0.77 LW	r = .978	Ashley 1963
Cotton[a]	A = 0.65 LW	r^2 = .998	Eide 1964
Grass (4 species)	A = 0.905 LW_m		Kemp 1960
Peanuts	A = .790 LW	r = .946	
Soybean	A = .655 LW	r = .988	
Sweet Potato	A = .644 LW	r = .987	
Timothy	log A = log L + log W — log K	S_e = 7 to 9.5%	Lal and Rao 1950
Tobacco	A = 0.634 LW	r^2 = > .99	Suggs et al 1960
Tobacco (small)	A = 0.703 LW	r^2 = .998	Suggs et al 1960
Turnips	A = 0.99X + 0.8	r = .98	Milthorpe 1956

L = maxium length
W = maximum width
W_m = width at L/2
X = "leaf dimensions," exact nature unspecified
K = LW_m/A

[a] *Determined from plants grown in a growth chamber.*

A most convenient method of measuring leaf area is by measurement of leaf dimensions. **Table 1** shows the relationship between leaf length, leaf width and leaf area for a number of crops. Although the accuracy of such measurements is quite acceptable for most studies of plant growth, a considerable amount of time is required and the method offers no convenient means for monitoring growth.

Plant height has been correlated with total leaf area (Newcom, 1963) for burley tobacco. Devices for monitoring plant height, called contact auxanometers, have been developed. However, all require a rather cumbersome support system for repositioning the sensing element as the plant grows.

Therefore, studies were initiated to see if stem diameter could be correlated in some way with total leaf area. This would allow measurement of plant growth at a fixed point on the plant.

Measuring Procedure

Stem diameter was measured with a machine micrometer at the first internode above the soil surface. Leaf area was determined using the leaf length-width relationships

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shown in **Table 1.** Leaf area measurements for peanuts, soybeans and sweet potatoes were determined from tracings of about 20 leaves from field grown plants. Leaf area was measured with a planimeter.

Relationship Between Stem Diameter and Leaf Area for Tobacco

Experimental Procedure

In the first test (Beeman, 1966) three plants of tobacco (*Nicotiana tabacum L.*, c. v. Hicks) were grown in a growth cabinet under a 24-hour light period. Plants were measured every other day. Two stem diameter readings were taken 90° apart. In the second test 13 plants were measured in a field test plot of *Nicotiana tabacum L.*, c. v. Coker 316 plants. The field plants were measured twice each week.

Results

The average stem diameter was plotted against leaf area as shown in **Figure 1.** The non-linearity of these curves suggested a logarithmic relationship; therefore, the data were plotted on log-log paper and found to be linear as shown in **Figure 2.**

A regression analysis between the logarithm of leaf area versus the logarithm of average stem diameter indicated that leaf area could be expressed as:

$A = 2620\ D^{2.726}$ with $r^2 = .995$ for growth cabinet plants, and

$A = 2148\ D^{2.862}$ with $r^2 = .986$ for field plants.

This relationship only holds up to the initiation of flowering. **Figure 3** shows the relationship between leaf area and stem diameter for a typical field plant showing that, upon initiation of flowering on about July 21, stem diameter continued to increase but leaf area actually decreased, due to progressive senescence of the lower leaves of the plant.

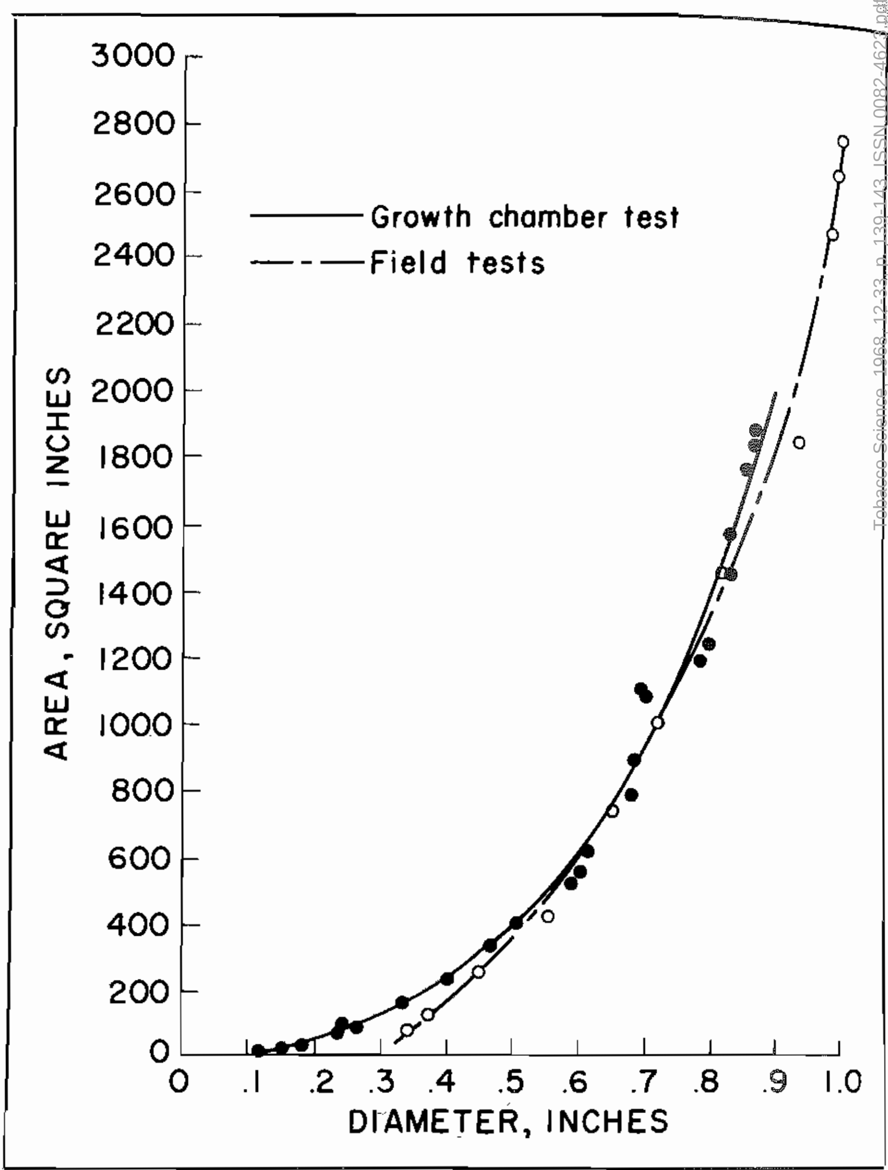

Fig. 1. Relationship between stem diameter and total leaf area for tobacco plants.

Table 2. Combination of Variables for Cultural Practices Test (N.C. 75)

Plant Population (plants/Acre)	Fertility Level (5-10-15, lbs/A)	Topping Height (Leaves)
8,000	1,000	18
12,250	1,000	18
3,750	1,000	18
8,000	1,500	18
8,000	500	18
8,000	1,000	no topping
8,000	1,000	12
10,500	1,300	22
10,500	1,300	14
10,500	700	22
10,500	700	14
5,500	1,300	22
5,500	1,300	14
5,500	700	22
5,500	700	14

Effect of Cultural Practices on the Stem Diameter-Leaf Area Relationship

Experimental Procedures

To determine the relationship between stem diameter and leaf area for various cultural practices, an experiment was set up to obtain a spectrum of plant sizes and shapes by varying plant population, fertility level and topping height of *Nicotiana tabacum L.*, c. v., N. C. 75. To measure possible interactions and to conduct the test in the most efficient manner a central composite, 3 dimensional experimental design with six observations at the center point was used (Cochran and Cox, 1957).

Results

Table 2 shows the combination of values for the three independent variables studied. Three individual plants, randomly selected from ten plants for each treatment, were measured twice each week through the growing season. For almost every treatment the breakover from a straight line, when leaf area and stem diameter were plotted on log-log paper, occurred at a stem diameter of 1 inch. For purposes of further analysis data for stem diameters greater than one inch were excluded. The values for eight consecutive readings of leaf area and stem diameter were subjected to regression analysis. Correlation coefficient, r, ranged between 0.931 and 0.997. The r values were transformed to Z values (Snedecor, 1948, pg 152, 153) and the t test was run to determine if the values of r were from the same population. There were no significant differences among the r values for plants within treatment or between plants across treatments at the 5% level. Therefore a response surface was not computed.

The standard deviation of the means for M and N in the relationship $A = MD^N$ was determined for each experimental combination and for the pooled mean. Only one plant, at the center point, was statistically different from the other 59 plants at the 1% level for both M and N and one other plant had a value of M which was statistically different from the general population at the 5% level. Therefore, all 60 plants responded essentially as if they were from a single population although plant population varied by over 3:1, fertilizer level varied by 3:1 and topping height varied from 12 leaves to no topping at all. Therefore all readings were pooled giving the relationship of the form $A = MD^N$ where

$A = 2150\ D^{2.97}$ with $r = 0.9735$, the standard error of estimate of $LnA = 0.2455$, the coefficient of variation of $LnM = 3.78\%$ and the coefficient of variation of $N = 12.74\%$.

The regression coefficient (N) represents the percentage change in the logarithm of leaf area for a one percent change in the logarithm of diameter. The correlation coefficient (r) represents the goodness of fit.

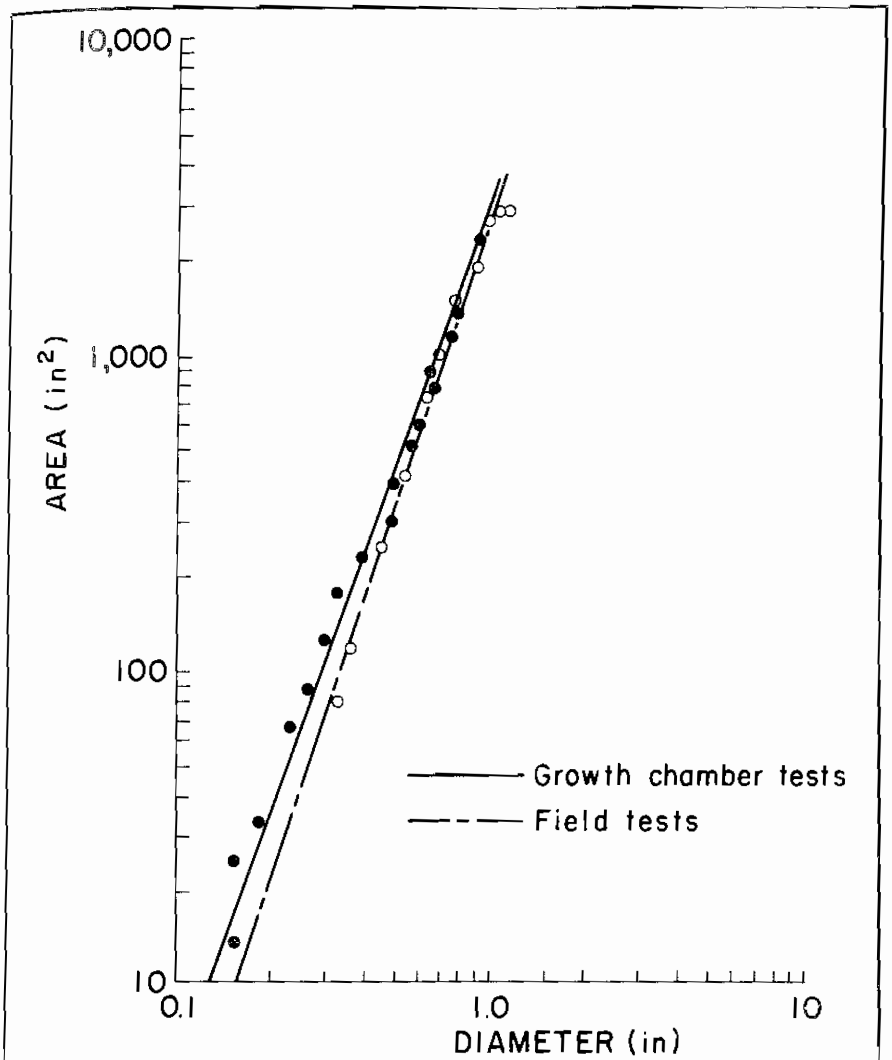

Fig. 2. Linear relationship between stem diameter and total leaf area when plotted on log-log scale.

Effect of Variety of Tobacco on the Stem Diameter-Leaf Area Relationship

Experimental Procedure

Ten plants each from four varieties were measured over one growing season and three more varieties were measured during another season. Seven consecutive readings, taken at weekly intervals, were subjected to a linear regression analysis of ln A on ln D.

Results

Except for Coker 319, there were no significant differences among

Table 3. Relationship Between Leaf Area and Stem Diameter for Seven Varieties of Tobacco

Variety	Regression Equation ($A=MD^N$)	Correlation Coefficient (r)	Standard Error of Estimate (Se) of LnA	Coefficient of Variation (%) LnM	N
Coker 316	$A = 1764.D^{2.486}$	0.974	0.337	2.35	9.69
Coker 139	$A = 2187.D^{2.563}$	0.980	0.296	2.68	7.26
Coker 319[a]	$A = 2803.D^{3.096}$	0.949	0.362	3.92	22.29
McNair 121	$A = 1809.D^{2.671}$	0.978	0.290	1.42	10.77
N. C. 75	$A = 2031.D^{3.074}$	0.987	0.218	1.97	4.22
N. C. 38359	$A = 1928.D^{2.661}$	0.973	0.260	3.20	9.24
Vesta 5	$A = 2002.D^{2.843}$	0.974	0.246	2.55	13.29

[a] *Plants within this variety were different at the 1% level.*

correlation coefficients or values of M and N for any plants within each variety at the 5% level. The ten plants for each variety were pooled and a regression analysis run. **Table 3** gives the leaf area equations, correlation coefficient, standard error of estimate and coefficient of variation for each variety.

Statistically, the regression coefficients (N) for Coker 316, Coker 139, McNair 121, N. C. 38359 and Vesta 5 were not different but r values for Coker 319 and N. C. 75 were different from all other varieties at the 5% level and from each other at the 1% level. The values of M and N were not different at the 5% level across all varieties except for Coker 319. Two plants of Coker 319 had values of M and N which were different from the general mean at the 1% level.

All seven varieties were pooled and the resulting regression equation was:

$A = 1977.4D^{2.698}$ with $r = 0.970$, $Se(\ln A) = 0.326$, $CV(\ln M) = 3.57\%$ and $CV(N) = 16.47\%$.

Although the N. C. 75 was grown in two different years for the cultural practice test and for the variety test the regression equations are nearly identical and there were no statistical differences between any of the parameter estimates of the regression equation.

Stem Diameter-Leaf Area Relationship for Other Plant Species Exhibiting Apical Dominance

Experimental Procedure

It was next of interest to determine if other plant species would exhibit this high correlation between leaf area and stem diameter. Cabbage, corn, cotton and cocklebur plants were grown in a growth chamber under alternate pink and blue fluorescent lights at a day temperature of 85° F and a night temperature of 70° F. The day period was 14 hours and the night period 10 hours.

Results

Fifteen cabbage plants, five corn plants, five cotton plants and four cocklebur plants were measured. **Table 4** shows the leaf area equations for cabbage, cocklebur, corn and cotton. Leaf area was determined using the LW relationship from **Table 1** and stem diameter was measured one inch above the soil surface twice each week. The corn stem tended to be elliptical in nature and it was found that the major axis of the stem gave a higher correlation with total leaf area than did the minor axis or the product of the two axes. Only one diameter measurement was taken for the cabbage, cotton and cocklebur instead of 2 as had been taken for tobacco and corn. Cabbage was found to have a direct linear correlation between leaf area and stem diameter for plants ranging from 5.4 to 109 square inches in leaf area. There were no significant differences between correlation coefficients or between values of M and N for the 15 cabbage plants at the 5% level.

Corn, cotton and cocklebur were found to exhibit an exponential relationship between stem diameter and total leaf area as did tobacco. The results are for corn plants with leaf areas ranging from 12 to 615 in², cotton plants with leaf areas ranging from 3 to 186 in² and cocklebur plants with leaf areas ranging from 3 to 93 in². There were no differences between regression coefficients or between values of M or N within plant types for all three plant types at the 5% level. All plant species were different from each other and from tobacco.

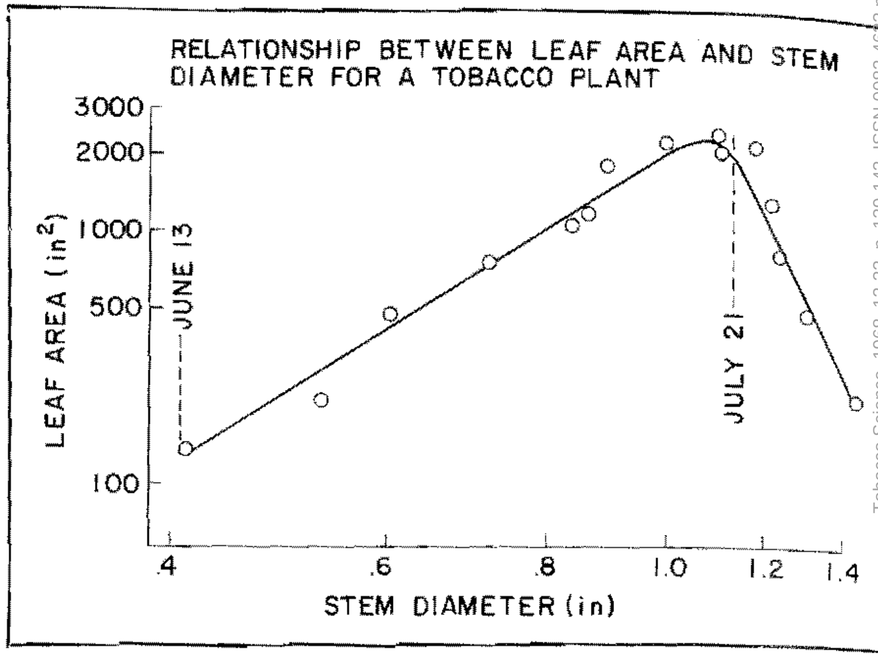

Fig. 3. Relationship between stem diameter and leaf area for a typical field plant showing the abrupt change with initiation of flowering.

Summary and Discussion

Stem diameter appears to offer a convenient index of total plant leaf area during the period of grand growth for plants exhibiting apical dominance. In general this relationship appears exponential although cabbage exhibited a linear response. The measurements for cabbage were not continued into the stage of head formation.

With the exception of one variety, differences between correlation

Table 4. Relationship Between Stem Diameter and Total Leaf Area for Four Plant Types

Plant Type	Regression Equation	Correlation Coefficient (r)	Standard Error of Estimate (Se) of LnA	Coefficient of Variation (C.V.)[a] M or LnM	N
Cabbage	$A = 862D - 64.6$ $= (MD-N)$	0.9725	0.0087	24.9	38.9
(*Brassica oleraces, Var. Capitata L.*, c. v. Market Topper)					
Corn[b]	$A = 1669.D^{2.703}$ $= (MD^{N})$	0.9905	0.1450	1.54	4.24
(*Zea mays L.*, c. v. DeKalb 1055)					
Cotton	$A = 22052.D^{3.232}$	0.9663	0.2880	8.11	4.07
(*Gossypium hirsutum L.*, c. v. McNair 1032)					
Cocklebur	$A = 14185.D^{3.100}$	0.9734	0.2049	3.66	4.07
(*Xanthium strumanium, Var. glabratum* D. C. Cronquest)					

[a] *The diameter for corn is the major axis.*
[b] *C. V. is for M for cabbage.*

coefficients or between M and N from the relationship $A = MD^N$ within varieties or between varieties of tobacco were not significant at the 5% level. Of 130 plants measured over 3 seasons only 3 plants deviated from the general mean at the 1% level. Pooling across varieties of tobacco yields a respectable correlation which may be adequate for many purposes although the coefficient of variation is increased. Relationships determined for a single variety for two seasons did not show a measurable change.

Our experience indicates that leaf area-stem diameter values for tobacco grown in a growth chamber do not apply exactly to field conditions or to different growth chamber environments (different light sources for example). Therefore it is recommended that a person using stem diameter as an index of total leaf area determine initial leaf area and final leaf area to check on the slope of the regression.

Utilizing stem diameter as an index has led to the development of an electronic micrometer which allows the detection of short term responses of plants to changes in environment (Beeman, 1966; Splinter, 1967). This equipment is capable of detecting changes in stem diameter of 1.5 microns. Detection of changes in plant growth in a matter of minutes is thus possible.

The utility of the stem diameter-leaf area relationships, along with electronic sensing devices, should greatly improve the ability of plant scientists and engineers to study plant growth.

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