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Use of Corn Plant Vegetative Characteristics and Other Factors in Predicting Production of Grain per Plant

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I. Introduction:

A major problem in the development of corn yield forecasting models has been predicting the weight of grain per ear at maturity for immature plants. Procedures in current forecasting models for predicting ear weight are limited to plots where the ears have progressed to at least the blister stage of development. A large portion, 97 percent in 1968, of the corn plants in the Corn Belt normally are not this mature (blister or later stages) at the time (July 22-29) of the August 1 corn objective yield survey. Therefore, the forecast yield computed at that time has been based upon an average weight of grain per ear from recent years.

An initial attempt to find vegetative plant characteristics which would be linked to final weight of grain was made in 1966 1/. At that time, observations were taken on four plants in each of five fields in each of six northern states. Correlations of the observed characteristics with final yield of grain per plant varied considerably by states.

Additional exploratory research in five corn fields in Howard County, Maryland was undertaken in 1968 in an effort to find vegetative and/or environmental characteristics which would be consistent estimators of weight of grain per plant at an early stage of development.

Since one of the characteristics under study was leaf area, a secondary objective was to find leaf measurements which could be used to accurately estimate actual leaf area.

II. Major Findings of this Study were:

(1) The area of a corn leaf blade can be satisfactorily estimated as a linear function of the product of the length and width of the leaf blade where the length is measured from the ligule to the tip and the width is measured at a point halfway between the ligule and the tip. The use of up to six additional width measurements does not appreciably increase the accuracy of the estimate.

1/ Unpublished report by Donald Von Steen, Research & Development Branch, S&RD, SRS, USDA.

(2) For the plants used in this study, many of the vegetative characteristics observed each week were significantly correlated with the productivity of the plants. This was true even for very immature plants (before the tassels emerged from the whorls). These characteristics included the areas of leaves at specific locations on the plant, measures of stalk size, and the number of viable (green) leaves on the plant.

(3) A forecast model which used measurements on a single leaf, the circumference of the stalk below the fifth node, and a count of viable leaves below the whorl from five plants per field would have predicted the average weight of grain per plant in each field with an average forecast error of about ten percent. This error was only one-fourth as great as the average error which would have resulted from using the average weight of grain per plant for all fields from previous years to estimate the average weight of grain for the individual fields.

If these relationships hold over years, they could be used to materially increase the precision of the August 1 objective estimates of corn yield.

(4) The effect of fertilizer applications, or of levels of fertilizer elements in the soil or in the plant tissues was not as well correlated with productivity as were some of the vegetative characteristics. For these fields, direct observations of plant characteristics were less costly and yielded more useful information than did fertility values. These plant characteristics reflect the effect of fertilizer applications and weather conditions that have prevailed to the time of observation.

III. Growth Characteristics of the Corn Plant:

The dent type of corn (sp. Zea mays, L.) commonly grown in this country is basically a grass with a jointed stalk. As with other grasses of this type, growth occurs through the production of a series of segments at the apical meristem (or growing tip) and the elongation of the internode portion of these segments. In the case of corn, this process terminates with the formation of a male flower (tassel).

At least one leaf (sometimes two) emerges from each node as it is formed. Leaves on succeeding nodes generally emerge on opposite sides of the stalk. Each leaf consists of (1) a sheath attached to the node and wrapped around the succeeding internodal portion of the stalk, and (2) a leaf blade which is joined to the sheath by the ligule.

Initially, any leaf sheath will elongate at a faster rate than will the next higher leaf sheath and the intervening innernode combined. Consequently, there will be a time when the ligule of the next higher leaf will be lower on the stalk than the ligule of the lower leaf. As long as this condition exists, the leaf blade of the next higher leaf will be held in a nearly vertical position. As many as 7 of the topmost leaves were observed in this condition on this study. Such a group of leaves is called a whorl.

The first, and sometimes the second, node from the base of the plant normally develop protuberances called brace roots. For this study, the highest node having brace roots was labeled the basal node. All higher nodes were numbered with respect to their relative position from the basal node.

While the average position of the ear or ears on the stalk is determined by the breeding of the particular variety, nearly all present commercial varieties have ears appearing somewhere between five to eight nodes above the basal node. The ears begin their development inside the leaf sheath. They are attached to a shank of connecting tissue which elongates until the ear is completely above the leaf blade. (For the remainder of this report, the term "ear" will be reserved for ears having at least one developing kernel, i.e., in at least the blister stage of development. Less mature ears will be referred to as ear shoots.)

If more than one ear shoot develops on varieties commonly grown in the North Central States, the second, third, etc. ear shoots will appear on consecutively lower nodes below the first. When more than one ear develops, the second ear is generally smaller than the first. Also, the second ear shoot has a smaller chance of producing an ear than does the first, the third ear shoot has a smaller chance of producing an ear than does the second, and so on.

As the tip of the ear shoot emerges from the leaf sheath, greenish "silks" on silk for each potential kernel, begin to emerge from the end of the ear shoot. Wind blown pollen shed by the tassels contacts the silks causing the kernels to be fertilized. After pollination, the silk dries up and turns a brownish color.

The existence of stress conditions with respect to soil moisture and/or soil nutrients is normally reflected first in the loss of the lower leaves of the plant. Stress conditions at pollination will result in poorly filled ears. This may result either from a shortage of viable pollen or from abortion of the individual kernels. Severe stress conditions at a later time will cause further development of some kernels to stop, beginning at the outer end of the ear.

IV. Field Procedures:

The five fields used for this study were selected to represent a range of planting dates, varieties, fertilization practices, and growing conditions. To further broaden the basis for the relationships found, observations were taken on plants in one of the "best" and in one of the "worst" rows in each field.

Weekly observations on the 5th, 15th, 25th, 35th, and 45th plants in each selected row started July 16-18 and ended August 13-14. Nearly all sample plants were in the pre-tassel stage of development at the time of the first visit. On the second and third visits, corresponding to the regular objective yield August 1 survey period, the majority of the plants had either ear shoots or ears in the pre-blister stage of development. Maturity of most plants at the time of the last weekly visit ranged from pre-blister through milk. (See Tables 1 and 2 for definations of maturity stages and distribution of sample plants by stage of maturity).

The mature ears were taken from the sample plants just before the fields were harvested for grain by the respective farmers.

Weekly observations included: (1) circumference of the stalk just below each node, (2) length and width measurements of the blade of each leaf not in the whorl, (3) condition of the tassel if present, (4) apparent stage of development, (5) the length of all ears as measured over the husk, and (6) the position of the ear(s) on the stalk. Leaf width measurements were taken at points one-fourth, one-half, and three-fourths of the distance from the base of the leaf to the tip. The descriptions used for classifying plants as to stage of development parallel those used on the regular objective yield survey. Portions of the regular objective yield criteria could not be used as they would have required removing portions of the husk and potentially affecting the development of the ear.

Additional data obtained for the sample fields included:

(1) Variety of corn planted and planting date

(2) Type, amount, and timing of any fertilizer applications

(3) On the first weekly visit, leaves on the tenth plant in each row were measured in the same manner as the other sample plants. The leaves were then stripped from the plants for additional measurements in the office.

(4) The top leaf below the whorl from plants immediately adjacent to the sampled plants was gathered on the first weekly visit for a tissue test.

(5) Soil samples were taken next to the tenth and fortieth plants in each row. These were also taken at the time of the first weekly observations.

Table 1.--Corn maturity codes, Maryland, 1968

Code	Description	Comparable objective yield classification
0	Tassel has not yet emerged beyond leaves in whorl.	Ear not yet formed
1	Tassel has emerged but no ears or ear shoots have emerged from leaf sheath.	Ear not yet formed
2	Ear shoot has emerged from leaf sheath but silks have not yet emerged from ear shoot.	Ear not yet formed
3	Some silks are showing at tip of ear shoot but no evidence of kernel formation.	Pre-blister
4	The presence of developing kernel(s) can be determined by feeling the ear (without stripping the husks back). Most silk protruding from husks are beginning to turn brown and dry.	Blister
5	Silks protruding from husks are brown and dry. Plants and husks are green. Ears are erect.	Milk
6	Husks are taking on a light rust colored appearance. Ears are beginning to lean away from the stalk.	Dough
7	Husks are dry or about dry and are starting to pull away from the ear, particularly at the tip. The ear feels firm and solid through husk.	Dent

Table 2.--Stage of development of sample corn plants by date of observation, Maryland, 1968

Stage of development	Maturity code	Number of plants by date of observation				
		July 16-18	July 24-25	July 30-31	August 6-7	August 13-14
		-- No ears or ear shoots present --				
Pre-tassel	0	39	13	11	6	2
Tassel	1	3	5	1	3	1
		-- Ears or ear shoots present --				
Silk not emerged	2		15		1	1
Pre-blister	3		10	31	18	8
Blister	4				15	4
Milk	5					27
Total		42	43	43	43	43
Maturity index 1/		0.1	1.5	2.2	3.0	4.8

1/ Computed as the mean of the products of maturity codes and the number of plants in that stage of development.

(6) All ears on the sample plants were picked at maturity for laboratory determinations of the production of shelled grain for each plant.

One row containing 5 sample plants in a portion of a field previously designated as to be harvested for grain was harvested for silage instead. Another two sample plants were destroyed by corn borers during the course of the survey so that complete sets of information were obtained for only 43 of the 50 plants.

V. Laboratory Procedures:

The soil and leaf tissue samples were analyzed by the Soils Laboratory at the University of Maryland. The leaf tissue test determined the proportion of phosphorus, potash, calcium, and magnesium in the plant tissues for each row. The soil samples were classified as to texture and tested to determine the P^H, magnesium, phosphate (P_2O_5), potash (K_2O), and organic matter levels. Results of these tests are included in Tables 8 and 9.

Outlines of leaves stripped from the tenth plant in each sample row were traced onto paper. These outlines were then planimetered. Width measurements were also taken at intervals of one-eight of the length of the individual leaves. The leaves were then air-dried and weighed.

Grain shelled from the mature ears was weighed and tested for moisture content. This information was used to compute the equivalent dry weight of grain per plant.

VI. Statistical Analysis:

(1) Statistical analyses made:

(a) Correlations between approximations of leaf area (the product of leaf length with various width measurements) and the planimetered areas of tracing of leaves from the tenth plant in each row were computed.

(b) Multiple correlation analyses were run using the dry weight of grain per plant as the dependent variable and vegetative characteristics (as measured each week) as the independent variables. The observations were grouped by week of observation and maturity of the plant at the time of the observation.

(c) A multiple regression analysis between dry grain weight per plant (dependent variable) and soil nutrient levels and properties (independent variables).

(d) A multiple regression analysis to examine the relationships between dry weight per plant and levels of plant nutrients in the leaf tissues.

(2) Estimating leaf area:

The true area of a leaf blade can be determined only by planimetering either the leaf or an outline of the leaf traced onto some material. Planimetering the leaf directly requires that it be removed from the plant being studied. It is possible to trace outlines of leaves without removing them from the plant but we have not yet been able to find a feasible way to do this without seriously damaging the leaves. The first part of the analysis then was to determine if we could find combinations of simple leaf measurements which would be highly correlated with the area determined by planimetering tracings of leaf outlines.

Measurements taken on the leaves were (1) the length of the leaf blade from the ligule to the tip, (2) the width of the leaf at a point halfway between the ligule and the tip, (3) the width of the leaf at points one-fourth of the leaf length from the tip and from the ligule, and (4) the width of the leaf at points located at a distance of 1/8, 3/8, 5/8, and 7/8 of the length from the ligule.

Correlations and F values were computed using combinations of these measurements and the corresponding leaf area determined by planimetering the leaf tracings. These correlations indicated leaf area could be estimated from only the length measurement. However, a significantly more precise estimate would be obtained by using the product of the leaf length and of its width at the mid point (Table 3). The precision of the estimate would not be appreciably greater if three or seven width measurements were used instead of one.

Weights of the air-dried leaves stripped from the tenth plant in each row were compared with the planimetered areas. The computed correlation of leaf weights with areas was significantly poorer than the correlation of planimetered area with the area computed from leaf length and width measurements.

The correlation between the planimetered leaf areas and the approximation obtained from the product of the length and width measurements where the width was taken at the middle of the leaf is very good. Thus, additional measurements do not make an appreciable contribution to the precision of the estimate. This approximation was used to compute estimated leaf areas for all analyses involving weekly observations of leaf area on the sample plants.

Table 3.--Correlations between combinations of corn leaf measurements and areas planimetered from leaf tracings, Maryland, 1968

Measurement	Coefficient of correlation	F
Length only	.769	98.7 1/
Length times width at mid point	.988	17.75 2/
Length times (width of leaf at mid point plus width at quarter lengths)	.991	1.35 3/
Length times (width of leaf at mid point plus width at quarter and at eights of leaf length	.992	1.13 4/

1/ The computed F-value tests the null hypothesis that the true regression coefficient b, in the model Y = a + bX is zero. $F_{.01}$ (1,68) = 7.02.

2/ The computed F-value tests the null hypothesis under the model Y = a + bX that the additional information included by computing X as the product of leaf length times its width at its mid point rather than using only the leaf length does not significantly increase the precision of the estimate. $F_{.01}$ (68,68) = 1.77.

3/ As 2/ except that the null hypothesis states that the additional information obtained by using three width measurements rather than one does not produce an appreciable increase in the precision of the estimate. $F_{.05}$ (68,68) = 1.49.

4/ As 3/ except that the null hypothesis states that the additional information obtained by using seven width measurements rather than three does not produce an appreciable increase in the precision of the estimate.

Table 4(a).--Corn vegetative characteristics tested for correlation with weight of grain per plant, Maryland, 1968

Variable: Name	Variable: Code	Description	When used
		Leaf numbers	
Measurable leaves	1	Number of measurable leaves (below whorl)	each week
Leaves in whorl	2	Number of unmeasurable leaves (in whorl)	each week
Total leaves	3	Total number of leaves on plant	each week
		Leaf size	
Maximum leaf area	4	Maximum leaf area	each week
Area - all leaves	5	Total area of all leaves below whorl	each week
Area - 4 lowest leaves	6	Total area of measurable, viable leaves on basal node and on the first three nodes above the basal node	each week
Area of leaves 5-8	7	Total area of measurable leaves from nodes 5, 6, 7, and 8	each week
Area of leaves 6-8	8	Total area of measurable leaves from nodes 6, 7, and 8	each week
Area of leaf 7	9	Area of leaf from node 7	each week
Length of leaf 7	10	Area of leaf from node 7	each week
Area - 4 highest leaves	11	Average area of top four measurable leaves (below whorl)	each week
Area - highest leaf	12	Area of top leaf (below whorl)	each week
Area - leaf above ear	13	Area of leaf above highest ear or ear shoot	ear or ear shoot present

Table 4(b).--Corn vegetative characteristics tested for correlation with weight of grain per plant, Maryland, 1968

Variable: Name	Variable: Code	Description	When used
		Stalk size	
Height of plant	14	Height of plant to highest node	each week
Circumference of fourth innernode	15	Circumference of stalk between nodes 4 and 5	each week
Circumference squared	16	Square of circumference of stalk between nodes 4 and 5	each week
Circumference below ear squared	17	Square of circumference of stalk below lowest ear	ear or ear shoot present
Difference between circumference squared above and below	18	Difference between squares of circumference below and above ear	ear or ear shoot present
Node with highest ear	19	Position of highest ear on stalk	ear or ear shoot present
Numbers of ears	20	Number of ears or ear shoots on stalk	ear or ear shoot present
Length of ears	21	Total length of ears measured over husk	ear or ear shoot present

(3) Correlation between plant characteristics and weight of grain produced:

The types of vegetative characteristics examined in this phase of the study were (1) number of leaves, (2) leaf sizes, (3) stalk sizes, and (4) ear characteristics. Particular characteristics were selected in the hope that they would reflect the relative vigor and potential productivity of the individual plants. Simple correlations by weeks of selected vegetative characteristics with weight of grain produced per plant are listed in Table 5.

(a) Number of viable leaves per plant:

The leaves on each plant were classified each week as to whether or not they were too tightly clustered in the whorl for the leaf blade to be measured. The correlation between the number of measurable leaves each week with the final weight of grain per plant was significant beyond the 99 percent level of probability each week of the survey. When individual maturity categories were considered, the correlations for plants in the pre-tassel and tassel stages of maturity were still significantly high. This was not true for plants in the more advanced categories.

The number of leaves too tightly clustered in the whorl to be measured as of a particular date was inversely correlated with the final weight of grain per plant. The correlation was relatively insignificant when most plants were in the pre-tassel stage of development. At this time, such plants had about the same number of leaves in the whorl.

The total number of leaves on the plant at a particular time was also highly correlated with the final weight of grain per plant. However, the correlation was not as good as for the number of measurable leaves.

(b) Leaf size:

The total measurable leaf area of each plant was computed each week. The largest of these weekly totals was defined as the maximum leaf area of that plant. The maximum leaf area was quite highly correlated with the weight of grain per plant, (r = .84). For the 43 plants in this study, maximum leaf area "explained" 70 percent of the variation in final grain weight per plant. Correlations of the weekly totals of measurable leaf area with final grain weight were also significantly high.

Table 5.--Simple correlations of selected corn vegetative characteristics with weight of grain per plant, and maturity index, by period of observations, Maryland, 1968

Variable 1/	Period of observation				
	July 16-18	July 24-25	July 30-31	August 6-7 2/	August 13-14 2/
	Maturity index 3/				
	.07	1.51	2.19	2.98	4.83
	Coefficients of correlation (r) 4/				
Leaf numbers					
Measurable leaves	.69	.71	.70	.65	.53
Leaves in whorl	-.16	-.58	-.57	-.44	----
Total leaves	.55	.66	.69	.58	.53
Leaf size					
Maximum leaf area	.84	.84	.84	.84	.84
Area - all leaves	.71	.77	.83	.85	.84
Area - 4 lowest leaves	.67	.73	.82	.80	.64
Area of leaves 5-8	.68	.71	.77	.77	.71
Area of leaves 6-8	.66	.69	.76	.77	.72
Area of leaf 7	.64	.60	.75	.77	.71
Length of leaf 7	.57	.49	.63	.72	.62
Area - 4 highest leaves	.76	.44	.32	.53	.64
Area - highest leaf	.80	-.14	-.16	-.06	.39
Stalk size					
Height of plant	.56	.62	.67	.70	.58
Circumference of fourth innernode	.74	.66	.73	.52	.44
Circumference squared	.69	.68	.72	.51	.43

1/ See Table 4 for more complete description of variables.
2/ Correlations computed only for 40 plants with ears or developing ear shoots.
3/ Maturity index is the weighed average of maturity codes, weighed by the number of plants in each maturity group.
4/ For the given number of observations, r greater than .30 indicates that the computed correlation is significant at the five percent level, r greater than .39 is significant at the one percent level.

The possibility of reducing costs by using measurements for only a few leaves per plant rather than for all leaves was tested. Sets of leaves considered for this purpose were:

(i) Leaves on the basal node and on the first three nodes above it,

(ii) Measurable leaves on nodes five through eight, and

(iii) The four highest measurable leaves on the plant

Ears normally emerge from nodes 5, 6, 7, or 8. Also, leaves from these nodes usually are among the largest on the plant. Therefore, again with hope of further reducing costs, the set of leaves on nodes five through eight was further divided into subsets of leaves on nodes 6, 7, and 8 and on node 7 only.

For plants in the tassel and pre-tassel stages of development, either the area of the four highest measurable leaves, or the area of the highest measurable leaf, was more highly correlated with final weight of grain per plant than any of the other leaf characteristics considered. Either variable would have reduced the mean square error of the estimate for those plants by over fifty percent. Both variables, particularly the area of the highest measurable leaf, were less useful when taken from more developed plants.

The total area of leaves remaining on the four lowest nodes became the most important measurement of leaf area once the first ear shoot had emerged from the leaf sheath. It was also nearly as good as the area of the four highest measurable leaves for plants in the tassel and pre-tassel stages of development. The correlation of this estimator with final weight of grain per plant was highly significant both for plants grouped both by individual weeks and by maturity stages within weeks. The rationale for this estimator appears to be that any stress conditions which would reduce the productive capacity of the plant, even at a very early stage of development, are reflected in the loss, either of entire leaves or in the loss of viable area from leaves borne on the lower nodes.

The various combinations of areas of leaves from nodes 5, 6, 7, and 8 were also highly correlated with weight of grain per plant. Unfortunately, leaf size in the early maturity categories was also correlated with the

Table 6.--Means ($\bar{X}$) and standard deviations (s) of selected corn vegetative characteristics, by period of observations, Maryland, 1968

Variable name 1/	July 16-18		July 24-25		July 30-31		August 6-7		August 13-14	
	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
	43		43		43		43		40	
Measurable leaves	7.8	2.0	10.7	3.3	10.9	3.2	11.3	2.2	11.6	1.7
Leaves in whorl	5.2	.9	2.7	2.0	1.0	1.8	----	---	----	---
Total leaves	13.0	2.0	13.4	1.8	11.9	1.7	----	---	----	---
Maximum leaf area	1229.1	409.6	1229.1	409.6	1229.1	409.6	1229.1	409.6	1229.1	409.6
Area - all leaves	860.4	386.1	1130.6	509.1	1157.3	448.3	1212.7	337.4	1177.5	439.8
Area - 4 lowest leaves	206.5	77.3	204.5	87.0	171.8	96.8	58.1	34.1	58.5	36.0
Area of leaves 5-8	438.1	253.5	504.9	196.3	532.5	161.9	134.5	36.7	138.7	33.1
Area of leaves 6-8	314.1	210.3	367.3	167.5	396.7	127.8	134.8	35.6	138.8	32.7
Area of leaf 7	112.8	72.7	121.3	61.6	134.8	44.0	136.6	36.8	139.6	31.8
Length of leaf 7	27.2	16.8	29.9	13.9	33.3	8.6	33.9	5.3	34.3	4.9
Area - 4 highest leaves	128.6	39.9	93.0	24.4	81.4	28.1	74.3	23.1	68.8	22.3
Area - highest leaf	129.8	32.0	63.3	38.9	45.3	36.3	34.9	21.0	25.6	12.5
Height of plant	37.0	16.7	57.0	26.0	62.8	25.9	66.3	22.3	70.4	18.4
Circumference of fourth innernode	2.7	.7	3.0	.6	2.9	.6	2.9	.6	2.8	.6

1/ See Table 4 for more complete description of variables.

stage of maturity. Therefore, correlations within maturity categories often were not significantly large.

The area of the leaf immediately above the highest ear or ear shoot has the desirable features that (1) the leaf is easily located; and (2) since a large portion of growth of this leaf occurs at the same time that the ear is starting its growth, the area of this leaf should reflect growth conditions at that time. This variable was tested for only the 31 plants in the pre-blister stage of development July 30-31. For those plants, the computed correlation was highly significant. (See Table 7).

(c) Stalk size:

Measures of stalk size considered for all weeks of this study were height of the plant to the highest node, the circumference of the stalk taken at the fourth innernode, and the square of the circumference at the fourth innernode. Additional variables evaluated only for the pre-blister stage for the July 30-31 period were:

(i) The square of the circumference of the innernode below the lowest ear.

(ii) The difference between squares of circumferences of innernodes taken above and below any ears.

(iii) The number of the node bearing the highest ear or ear shoot.

(iv) The number of ears or ear shoots on the stalk.

The measure of stalk size which was most closely correlated with final grain weight for plants in the pre-blister stage was the square of the circumference below the lowest ear (variable 17). Surprisingly, this variable was even considerably better than the square of the circumference at the fourth innernode. Other measures of stalk size which were highly correlated with final weight of grain per plant were the differences in the squares of the circumferences taken above and below the ears, the number of ear shoots, and the circumference at the fourth innernode.

The square of the circumference of the stalk was introduced into the analysis in the hope that, as a linear function of the cross-sectional area, it would provide a better measure of potential productivity.

Our experience with the 1968 data does not support this assumption. The correlations obtained using the circumference squared were very little different (and generally no better) from those obtained using only the circumference. Therefore, it does not seem that functions using the square of circumferential measurements need to be considered in future studies.

Correlations using height of plants were significant only at the five percent level. However, this variable was the best one to use in a multiple regression estimator with the square of the circumference below the lowest ear.

Correlations of plant height and circumferences with weight of grain generally were higher when computed from plants in all maturity categories for a given week than when the categories were examined separately. As with leaf size, this probably happened because of the difference in the average values of the different maturity categories.

(4) Correlations between soil nutrients and grain production:

Fertility values from the soil tests - M_g, P, K_2O, organic matter, and p_H - were correlated with the average weight of grain from the two plants closest to the soil sample. For these factors and fields, only the percentage of organic matter in the soil was significantly correlated at the five percent level with weight of grain produced. The correlation between the magnesium content and grain produced was almost but not quite significant.

Considering the comparatively low correlations observed for soil samples from the field and the amount of time required to process the samples in the laboratory, it seems unlikely that soil tests will be of much value for forecasting corn yields.

(5) Correlations between levels of plant nutrients in leaf tissue and grain production:

The highest correlation of fertilizer elements in the plant leaves with weight of grain per plant was for phosphorus. The computed correlation ($r = 0.43$) was significantly large at the one percent level. The percentage of calcium present in the leaf tissue was also significantly correlated (at the five percent level) with weight of grain per plants. The correlation of the percentage of magnesium present with weight of grain was almost as good as for calcium but was not quite enough to be statistically significant.

Table 7.--Means and standard deviations of selected corn vegetative characteristics and linear coefficients of correlation of these variables with weight of grain per plant, 31 plants in pre-blister stage of ear development, Maryland, July 30-31, 1968

Variable code 1/	Mean	Standard deviation	Coefficient of correlation 2/ (r)
Area of leaf above ear	146.75	22.92	.58
Height of plant	76.28	15.58	.38
Cir			
Circumference at four innernode	2.80	.71	.49
Circumference squared	8.33	4.20	.48
Circumference below ear squared	9.54	3.31	.71
Difference between squares of circumferences above and below ears	3.63	1.60	.64
Node with highest ear	6.94	.77	.17
Number of ears	1.58	.62	.56

1/ See Table 4 for description of variables.

2/ Coefficients of correlation computed from 31 observations would be significantly large at the five percent level if they exceeded 0.355, at the one percent level if they exceed 0.456.

Table 8.--Means, standard deviations and linear correlations of soil test values with weight of grain produced for corn, Maryland, 1968

Factor	Mean	Standard deviation	Linear correlation with weight of grain per plant
Organic matter	1.97 percent	0.30 percent	-0.39*
Magnesium (M_g)	126	54	0.30
Potash (K_20)	79	43	-0.19
Phosphorus (P_20_5)	63	65	0.18
Soil acidity (P_H)	6.59	.39	0.04

* Correlation was significantly large at the five percent level of probability, 30 d.f.

Table 9.--Means, standard deviations, and linear correlations of leaf tissue elements with weight of grain produced for corn, Maryland, 1968

Element	Mean	Standard deviation	Linear correlation with weight of grain per plant
	%	%	
P	0.294	0.036	0.431**
C_a	0.432	0.095	0.316*
M_g	0.293	0.073	.0294
K	2.065	0.542	-0.240

** Statistically significant beyond the one percent level of probability. ($r_{.01(40df)}$ = 0.393)

* Statistically significant beyond the five percent level of probability. ($r_{.05(40df)}$ = 0.304)

Table 10.--Fertilizer applications, levels of soil fertility, leaf tissues test results, and average weight of grain produced per corn plant, by fields and rows, Maryland, 1968

Field	Fertilizer applied 1/			Row	Soil test results					Leaf tissue test results				Average weight of grain per plant
	N	P_2O_5	K_2O		Mg	P_2O_5	K_2O	Organic matter	pH	P	K	Mg	Ca	
										%	%	%	%	-grams-
1	15.0	30.0	30.0	1	103	47	105	2.4	6.0	.24	2.7	.29	.39	109.25
				2	70	35	89	2.2	6.0	.22	2.1	.27	.27	20.01
2	27.5	55.0	55.0	1	224	145	88	1.8	6.7	.24	2.5	.21	.24	2/
				2	224	180	92	1.7	6.6	.33	2.4	.23	.36	200.47
3	90.0	90.0	90.0	1	184	20	42	1.7	7.2	.27	2.1	.29	.47	89.28
				2	95	20	44	2.1	6.6	.35	2.3	.27	.40	144.42
4	32.5	65.0	65.0	1	129	22	46	1.8	6.8	.30	1.4	.42	.55	165.04
				2	96	40	33	1.8	7.0	.30	1.0	.40	.60	151.72
5	30.0	30.0	30.0	1	86	50	118	2.0	6.4	.32	2.4	.27	.39	109.44
				2	112	128	136	2.2	6.5	.28	2.3	.21	.33	46.60

1/ Actual pounds of nutrients per acre

2/ Row 1 of field 2 was harvested for silage

VII. Model Development:

A simple general purpose forecast estimator is the linear regression model (1), $Y_i = a + b X_i$. Using this model as a forecast estimator assumes that some characteristic (X_i) which is associated with the value being predicted (Y_i) can be observed at some time before the Y characteristic can be measured. (In this study, the Y characteristic would be the weight of grain per plant at maturity and the X characteristic could be any one of several measures of leaf size, plant size, or ear characteristics). The parameter "b" (coefficient of regression) is a measure of the linear rate of change in Y as compared with X. The parameter "a" is an estimate of the point at which the regression line crosses the y-axis, i.e., the value of Y when X becomes zero. Both "a" and "b" are estimated by a least-squares procedure from data collected in earlier years.

If the estimated value of "a" is not significantly different from zero, then the regression model (1) is analagous to the ratio model (2), $Y_i = R X_i$, where "R" is the ratio $\Sigma Y/\Sigma X$, and ΣX and ΣY come from previous surveys.

The relationship between the X and Y characteristics probably will not be linear over the entire range of possible values. To the extent that the lack of linearity results from the interaction of time or of maturity, the model can be limited to portions of the response curve which are approximately linear through appropriate stratification or classification into maturity categories. (See Figure 1.)

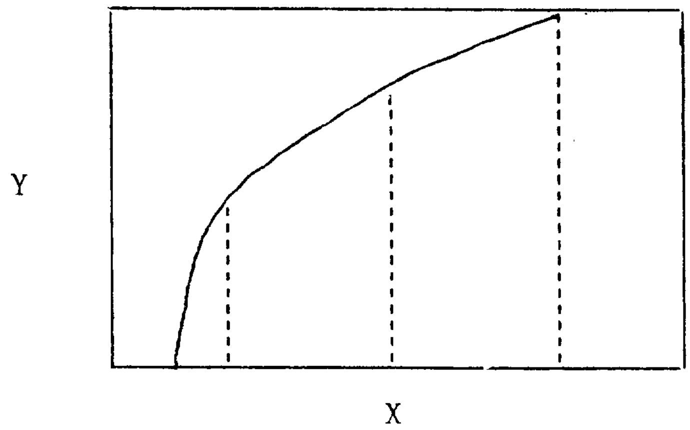

Figure 1.--Hypothetical example of dividing a non-linear response curve into sections of approximate linearity.

This procedure changes model (1) to:

(3) $Y_{ji} = a_j + b_j X_{ij}$, where the j subscript is for a particular strata or maturity classification.

The experimentor often finds that two or more "X" characteristics can be used to predict "Y". If the cost of obtaining the additional information is not too great, he may

(a) Compute separate estimates of "Y" for each of the "X" characteristics and then combine the separate estimates in some manner; or

(b) Compute a single estimate of "Y" using the several "X" characteristics in a linear multiple regression model as

(4) $\hat{Y}_{ji} = a_i + b_{1j} X_{1ji} + b_{2j} X_{2ji} + b_{mj} X_{mji}$

$$\text{or } \hat{Y}_{ji} = a_j + \sum_{k=1}^{m} b_{kj} X_{kji}.$$

A particular advantage of using more than one "X" characteristic in predicting Y is that we usually obtain a more precise estimate (in terms of forecast error) when using several "X" characteristics than we use only one.

The decision as whether to use separate estimates of "Y" weighed together in some optimum fashion or a single multivariate estimation model would be determined principally by the source of the data used in computing the parameters for the prediction equations. Separate estimates will be required whenever the different "X" values come from at least partially different sources. However, there can be a slight computational advantage in using the multiple linear model whenever the different "X" values are fully paired.

The stepwise analysis of the data showed (See Table 11) that the area of leaves remaining on the four lowest nodes (variable 6) was most consistently the best variable of those tested. Other characteristics which were useful at different times were:

(a) Variable 12, the area of the highest measurable leaf for plants the first survey period, July 16-18, when most plants were in the pre-tassel stage of development and had an average of only 7 to 8 measurable leaves per plant.

(b) The number of measurable leaves (variable 1)

(c) The height of the plant to the highest node (variable 14)

(d) The circumference (or the square of the circumference) below the ear or below the fifth node (variable 15, 16, or 17).

I would emphasize that these relationships were found in data collected from a small number of fields in 1968. There is no quarantee that these relationships will hold over years or in other areas. Above all, a useful model must be consistent over years.

No attempt has yet been made to predict the weight of grain per plant from different fields or different plots in the same field. The proposed model will be tested on similar data collected from the same area of Maryland in 1969.

Table 11.--Best sets of variables in multiple correlation models for predicting final weight of grain per plant for corn (in grams), by period of observation and selected maturity stages, Maryland, 1968

Period of observation	Stage of maturity (code)	Weight of grain per plant			Best set of Variables 1/	Coefficient of correlation	Standard error of estimate
		N	Mean	S.E.			
July 16-18	All	43	116.1	68.8	12,6,1	.88	34.5
	pre-tassel	40	115.9	71.2	12,6,	.85	38.4
July 24-25	All	43	116.1	68.8	6,16,11,1	.86	37.9
	Pre-ear	18	63.7	57.8	11,4	.92	23.9
	Silk	15	151.5	51.5	6,19,13	.93	21.3
	Pre-blister	10	157.2	46.5	1,17,18	.88	26.5
July 30-31	All	43	116.1	68.8	6,15,14	.87	35.2
	Pre-blister	31	133.0	58.6	6,1,14	.88	29.6
Aug. 6-7	All	40	124.8	63.1	6,1,11	.86	33.7
	Pre-blister	16	137.6	47.8	6,19	.87	25.0
	Blister	15	142.2	65.2	13,18,14	.94	25.2
Aug. 13-14	All	40	124.8	63.1	15,6,14	.88	30.9
	Earlier than milk	13	84.6	62.7	8	.91	27.7
	Milk	27	144.1	54.4	6,16,14	.86	30.0

1/ Variables are listed in the order given by a stepwise regression. See Table 4 for definitions of variable codes.

Table 12.--Parameters for predicting weight of grain per plant for corn by weeks and stages of maturity within weeks, Maryland, 1968

Week	Stage of maturity	Mean	Independent variables 1/					
			X_1	X_6	X_{21}	X_{11}	X_{14}	X_{15}
			- Multiple regression coefficients -					
July 15-17	All	-126.72	0	.290	.260	0	0	28.02
July 22-24	Pre-ear shoot	-118.06	0	0	0	1.417	1.417	0
	Ear shoots	-116.97	13.086	.427		0	0	0
July 29-31	Pre-ear shoot	-85.60	0	.156	0	.602	2.612	0
	Ear shoots	-284.8	22.47	.318	0	0	.982	0
Aug. 6-7	Pre-blister	-271.1	22.01	.249	0	0	1.29	0
	Blister	-205.0	0	.341	0	0	1.73	54.85
Aug. 13-14	Pre-milk	-175.76	0	0	0	0	1.651	65.81
	Milk	-315.04	10.39	.186	0	0	1.717	57.37

1/ See Table 4 for definition of codes.

Appendix A: Field Characteristics

Field 1

Size	9.0 Acres
Soil type	Loam
Date planted	May 22
Variety	Pioneer 312A
Fertilizer applied (actual pounds per acre)	15.0 N, 30.0 P_2O_5, 30 K_2O
When applied	at or before seeding
Plant population (July 15-18)	15,862
Average weight of grain per plant	64.63 grams

Field 2

Size	16.0 Acres
Soil type	Loam
Date planted	May 25-31
Variety	Pioneer
Fertilizer applied (actual pounds per acre)	27.5N, 55.0 P_2O_5, 55 K_2O
When applied	at or before seeding
Plant population (July 15-18)	10,546
Average weight of grain per plant	200.47 grams (row 2 only)

Appendix A (Cont'd)

Field 3

Size	24.0 Acres
Soil type	Loam
Date planted	May 9
Variety	Pioneer 346
Fertilizer applied (actual pounds per acre)	90.0N, 90.0 P_2O_5, 90.0 K_2O
When applied	at or before seeding
Plant population	21,139
Average weight of grain per plant	113.79 grams

Field 4

Size	---
Soil type	Loam
Date planted	---
Variety	DeKalb
Fertilizer applied (actual pounds per acre)	32.5N, 65.0 P_2O_5, 65.0 K_2O
When applied	at or before seeding
Plant population (July 15-18)	19,295
Average weight of grain per plant	158.38 grams

Appendix A (Cont'd)

Field 5

Size	6.0 Acres
Soil type	Loam
Date Planted	May 5
Variety	Pioneer 3304
Fertilizer applied actual pounds per acre)	30.0N, 30.0 P_2O_5, 30.0 K_2O
When applied	at or before seeding
Plant population (July 15-18)	11,210
Average weight of grain per plant	81.51 grams