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KENAF LEAF DEVELOPMENT AND STEM HEIGHT INDEX OF CROP YIELD IN THE UNITED
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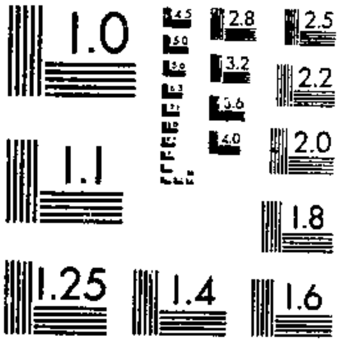

MICROCOPY RESOLUTION TEST CHART
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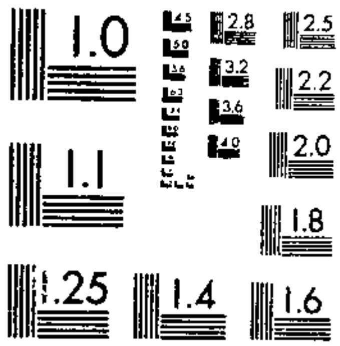

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KENAF LEAF DEVELOPMENT AND STEM HEIGHT: INDEX OF CROP YIELD IN THE UNITED STATES

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CONTENTS

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KENAF LEAF DEVELOPMENT AND STEM HEIGHT: INDEX OF CROP YIELD IN THE UNITED STATES

By JOSEPH J. HIGGINS, *plant physiologist, Germplasm Resources Laboratory, Northeastern Region, Agricultural Research Service*[1]

SUMMARY

The objective of this study was to determine the usefulness of kenaf leaf development and stem height as measures of response to environment and as indicators of leaf and stem yield. This information was subsequently used to estimate stem yields that might be expected for different locations in the United States. The leaf development stage is defined as the total number of leaves found on the main stem, including the fractional stage of development of the actively unfolding new leaf, at a given time.

In a series of planting and harvest date experiments, leaf development stage and stem height were related to leaf and stem yield at Glenn Dale, Md. The largest stem yield of 17.1 metric tons per hectare occurred in 1962 at a leaf development stage of 87 stem leaves. The maximum production rate of stem yield in relation to leaf development stage occurred in 1968. The linear regression was $\hat{Y} = -3.434 + 0.25440X$, where $\hat{Y}$ = expected metric tons per hectare and X = leaf development stage. In an average growing season 15.5 metric tons of stems per hectare may be expected for plants with 75.7 leaves.

Simple and multiple regressions of leaf development and stem height against several environmental variables showed significant relationships, but effects varied between years and with sites of temperature measurement within the crop.

The relationship between leaf development and temperature was determined graphically. Then daily leaf development was calculated for many locations in the United States by using temperature records and was converted to stem yield. A comparison of calculated and observed stem yields for several widely scattered

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[1] Now with Grain Division, Agricultural Marketing Service.

Although the data on which this bulletin is based were collected during 1961–69, the findings are still valid and useful as guidelines for developing additional research on predicting kenaf yields.

plantings showed surprisingly little differences in a number of instances.

Stem yields per hectare may be more than 45 metric tons (20 tons per acre) in southern Florida and Texas and at least 22–28 metric tons (10–12.5 tons per acre) as far north as eastern North Carolina under conditions of adequate fertilizer, soil moisture, and good cultural practices.

Harvestable leaf yields at Glenn Dale reached 3,458 kg. per hectare during the early summer of 1968 at a leaf development stage of 61 stem leaves. Yields were reduced later in the season because larger leaves began to absciss in the lower part of plants and newly formed leaves were smaller. Approximately 2,300 kg. of leaves per hectare may be harvested just before frost.

INTRODUCTION

Kenaf (*Hibiscus cannabinus* L.), a promising new annual source of raw material for paper pulp, responds strikingly to the environment. In test plantings, stem yields per hectare have varied from 6.27 metric tons (2.8 tons per acre) at Rosemount, Minn., to 34.07 metric tons (15.2 tons per acre) at College Station, Tex. (*8, 9*).[2]

The objective of this study was to demonstrate the usefulness of quantitative observations of leaf development and stem height as measures of plant response to environment and as indicators of leaf and stem yield. A second objective was to estimate potential stem yields for different locations in the United States.

The leaf development stage is defined as the total number of leaves produced along the main axis or stem of the plant, including the fractional stage of development of the actively unfolding new leaf, at a given time. This is a relatively new approach for recognizing plant responses to environmental variables.

Higgins and Decker (*3*) reviewed leaf development research. In 1952 Higgins (*1*) described a detailed method that divided the development of a single leaf of garden pea into a series of 10 stages indicated by decimal fractions. This method has been briefly described for kenaf (*2, 4, 7*).

Higgins and others (*5*) showed that mean temperature, day length, radiation, and soil moisture significantly affected the development of new leaves at the terminal growing point for kenaf, *Tephrosia, Crambe,* and corn. Plant responses lagged behind

[2] Italic numbers in parentheses refer to Literature Cited, p. 30.

environmental variables. However, stem or leaf yields and stem height were not included in these studies.

Higgins and Decker (*3*) in studies with *Tephrosia* found in a simple regression analysis that daily leaf development was highly correlated linearly with temperature and radiation. Stem height measurements were not correlated with these parameters. In a multiple regression analysis, maximum temperature and evapotranspiration were highly significantly correlated with leaf development. Including other variables did not significantly account for any additional variation in development. After establishing a relationship between leaf yields and leaf development, yields were estimated for a range of Maryland climates.

PROCEDURE

Field Plots, Cultural Treatments, and Statistical Analysis

Seed of the kenaf cultivar Everglades 71 was planted in a Collington fine, sandy loam at the U.S. Plant Introduction Station, Glenn Dale, Md. A series of field experiments were made from 1961 to 1969 to study the effect of planting and harvest dates, plant population, and row spacing on growth and stem yield.

Planting, frost, and harvest dates are given in table 1. Rows were spaced 46 cm. apart in all years except 30 cm. in 1961 for the first eight planting dates and 36 and 53 cm. in 1969. Treatments were replicated three to four times during 1962–69 (none in 1961) in randomized block or split plot designs. Harvest areas were two to four rows and 3.6 to 4.4 meters long. Two or more border rows were used. Plants were fertilized with nitrogen, phosphorus, and potassium, averaging 200–72–114 kg. per hectare. Although irrigation was applied in most years at a rate to promote maximum growth, it may not have been adequate in years of severe drought.

Plant populations averaged 264,000 plants per hectare for all years. In 1966 and 1967, populations of 100,000, 200,000, 300,000, and 400,000 plants per hectare were studied (*6*).

Simple correlations were calculated between all combinations of leaf development stage, stem height, plant population, and stem yield for each replication for all years. A stepwise regression was calculated using stem yield as the dependent variable.

Leaf Development and Stem Height

Leaf development stage was recorded two to five times per week from 1961 through 1969 and stem height was measured when

TABLE 1.—*Ovendry kenaf stem yields for different planting and harvest dates, irrigation rates, and row widths, 1961–69*

Date of— Planting	Frost	Harvest	Stem yield
			Metric tons per hectare
1961			
May 18	Oct. 28	Nov. 15	12.9
25			13.2
June 1			11.1
8			12.4
15			12.6
23			14.6
27			10.3
July 12			9.6
27			5.1
1962 (WITH IRRIGATION)			
Apr. 16	Oct. 24	Nov. 28	17.1
May 4			16.0
17			13.6
June 4			10.8
25			8.2
1962 (WITHOUT IRRIGATION)			
Apr. 16	Oct. 24	Nov. 28	7.2
May 4			7.2
17			4.6
June 4			4.2
1963 (WITH FREQUENT IRRIGATION)			
Apr. 16	Nov. 4	Nov. 19	14.8
May 20			14.6
1963 (WITH LIMITED IRRIGATION)			
Apr. 16	Nov. 4	Nov. 19	10.8
May 20			11.4
1964			
Apr. 27	Oct. 11	Nov. 17	12.8
1965			
May 4	Oct. 5	Oct. 20	12.3
1966			
May 16	Oct. 18	Sept. 6	10.6
		Oct. 4	15.4
1967			
May 5	Oct. 20	Sept. 6	8.4
		Oct. 2	11.1

TABLE 1.—*Ovendry kenaf stem yields for different planting and harvest dates, irrigation rates, and row widths, 1961–69*—Con.

Date of— Planting	Frost	Harvest	Stem yield
			Metric tons per hectare
		1968	
Apr. 29	Oct. 30	July 12	1.9
		17	2.6
		22	3.1
		26	3.7
		31	4.5
		Aug. 6	6.4
		9	5.7
		13	6.8
		19	7.7
		23	8.4
		28	8.9
		Sept. 3	10.7
		9	9.9
		13	10.2
		19	13.1
		25	13.3
		Oct. 2	15.7
		8	15.3
		11	15.4
		15	14.8
		1969 (36-CM. ROW WIDTH)	
May 1	Oct. 18	July 29	4.5
		Aug. 7	5.9
		14	7.8
		21	7.9
		Sept. 4	9.7
		11	10.2
		1969 (53-CM. ROW WIDTH)	
May 1	Oct. 18	July 29	4.6
		Aug. 7	5.8
		14	8.3
		21	8.4
		Sept. 4	11.0
		11	9.9

leaf development stage was recorded from 1966 to 1968. Ten plants were tagged in each replication for observation. In 1966 to 1969, tagged plants were observed only for the last harvest date. At harvest, leaf development stage and stem height were recorded for 10 additional plants for each plot. Only stem height was measured from postfrost harvests.

The total number of leaves, including the fractional stage of the unfolding leaf, was recorded. In order to identify the exact number of leaves on each observational plant, the development of the unfolding leaf was divided into 10 stages. The unfolding leaf is that leaf for which the first fractional stage of leaf development occurs when the leaf margins have just become separated for their entire length. This method is illustrated in figure 1 and described as follows:

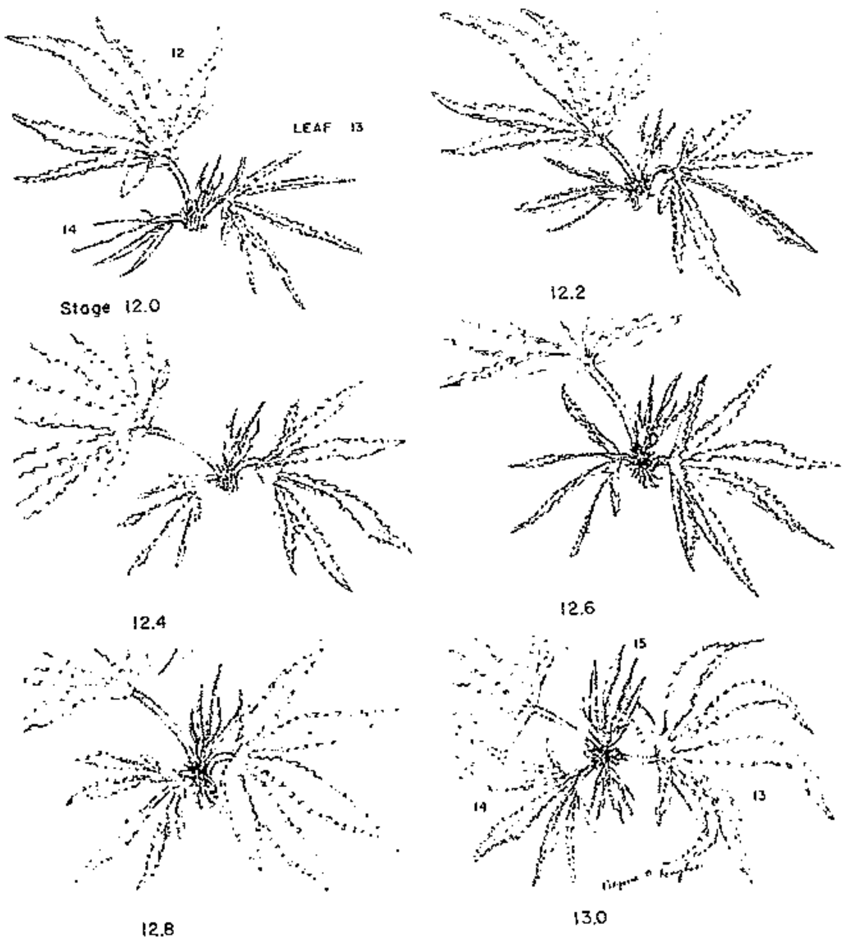

FIGURE 1.—Fractional leaf development stages of kenaf illustrated for the unfolding of leaf 13.

Stage *Description*

12.0—The lobe margins of leaf 13 have just become separated from tip to base of the leaf. The lobe margins of leaf 12 have greatly separated although the leaf is not fully flattened out.

12.2—The lobe margins of leaf 13 have further separated from each other.

12.4—The lobe margins of leaf 14 have begun to separate.

12.6—The lobe margins of leaf 14 have separated about one-half their length.

12.8—The lobe margins of leaf 14 have separated about three-fourths their length.

13.0—The lobe margins of leaf 14 have just become separated from tip to base of the leaf.

The intermediate stages were estimated from these descriptions. Brief descriptions of fractional leaf development stages have been published (*4*, *5*, *9*).

Climatological Observations and Statistical Analyses

Maximum and minimum temperatures in all years were taken from thermometers in a standard U.S. Weather Bureau shelter located near the research plots. Thermocouple temperatures (continuously recorded), evapotranspiration, radiation, and soil moisture (neutron method) were determined in 1967 and 1968 as previously described (*3*).

Simple linear correlation coefficients between all possible variables and six multiple regression analyses were calculated for three seasonal subsets—for 1967, 1968, and these years combined. No lag effects of plant responses to variables were calculated because plants were not observed daily. Mean and range in daily temperature and mean maximum temperature calculated for the highest temperature reached in ten 10-minute intervals were also included.

RESULTS

Crop Performance in Relation to Cultural Treatments

Stem yield per hectare varied from 14.6 to 5.1 metric tons for nine planting dates in 1961 and from 17.1 to 8.2 metric tons for five planting dates when irrigated in 1962 (table 1). In 1963 and 1966, yields per hectare reached approximately 15 metric tons, whereas in 1968 they increased for 20 harvest dates from 1.9 to 15.7 metric tons.

In order to determine the relative performance and vigor in all experiments, stem yield was plotted against leaf development stage (fig. 2). Stem yields in 1968 represent the maximum production rate for these experiments. The linear regression for yield in 1968 was $\hat{Y} = -3.434 + 0.25440X$, where $\hat{Y}$ = expected metric tons per hectare and X = leaf development stage. The correlation coefficient (r) was 0.9504. Yields in 1961, 1963, and 1969 were similar to the 1968 yield curve; however, yields per hectare for 1969 did not exceed 11 metric tons because of an early harvest. The two prefrost harvest dates in 1966 also fell on this line for 1968 and the April 16 and May 17 plantings in 1962.

In 1964, 1965, and 1967, when yields were below those of 1968, insufficient soil moisture probably had a retarding effect on yield. Although irrigation was applied in 1964 and 1965, it may have been insufficient. No irrigation was applied in 1967.

Under severe drought conditions in 1962, yields for irrigated plots were more than double those for nonirrigated plots. In 1963, yields for frequently irrigated plots were considerably higher than yields for plots with limited irrigation.

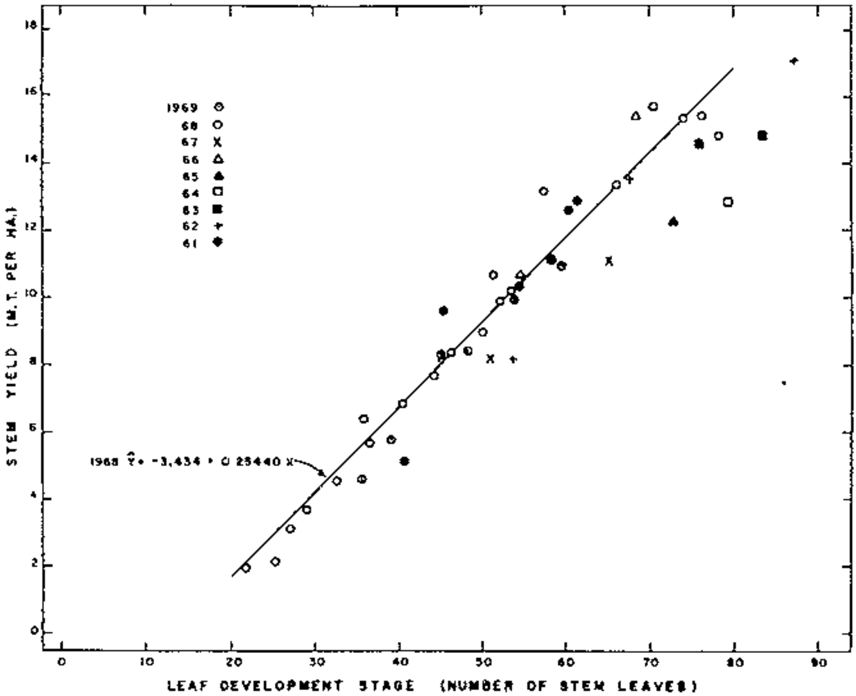

FIGURE 2.—Relationship between kenaf stem yield and leaf development stage at Glenn Dale, Md., 1961–69.

Kenaf stem yields were significantly reduced by delayed harvest after frost in 1966 and 1967 (*6*). In 1961, 1962, 1963, and 1964, when kenaf was harvested after frost, some yield reductions may have occurred.

Row widths of 36 and 53 cm. with approximately 260,000 plants per hectare in 1969 did not significantly affect stem yield. Although yield did vary with harvest date, there was no interaction of row space and harvest date.

In a stepwise multiple regression of kenaf stem yield against leaf development stage, stem height, and plant population for 1961–69, each variable significantly affected yield (table 2). The stage of leaf development accounted for the greatest variability in stem yield, whereas population accounted for more variability than did height.

TABLE 2.—*Stepwise multiple regression of kenaf stem yield (kg. per ha.) against 3 independent variables, 1961–69* [1]

Degrees of freedom (d.f.)	F ratio	Coefficient of multiple correlation squared (R^2)	Standard error of estimate	Constant	Partial regression coefficients of variables—		
					Leaf development stage	Stem height	Plant population
218	-------	--------	3,954	------------	--------	-------	-------
217	477.4**	0.6875**	2,215	−1,705.5422	208.7355	-------	-------
216	49.4**	.7457**	2,003	−7,984.9960	247.6770	-------	0.15723
215	31.9**	.7786**	1,873	−9,222.0781	187.6897	20.0996	.13547

[1] ** = statistically significant at 1-percent level.

Simple correlations for 1961–69 between all variables showed that population was least correlated with stem yield of the four variables:

Variables	*r values for variables* [1] 1	2	3	4
(1) Leaf development stage	1.000**	---------	---------	-------
(2) Stem height	.7619**	1.000**	---------	-------
(3) Plant population	−.5397**	−.3124**	1.000**	-------
(4) Stem yield	.8291**	.7755**	−.2444**	1.000**

[1] ** = statistically significant at 1-percent level.

Stem yield and height were highly correlated in several individual years. The highest correlation coefficient ($r = 0.9508$) and degrees of freedom (78) were in 1968 with the regression equation of $\hat{Y} = -6.125 + 0.06196X$, where $\hat{Y}$ = expected stem yield in metric tons per hectare and X = stem height in centimeters.

Correlation of Environment, Leaf Development, and Stem Height

Simple Correlation Analyses.—Temperature was correlated with daily leaf development at the 5-percent level in 1967 and was correlated with daily stem height at the 1-percent level in 1967 and 1968 (table 3).

Radiation, soil moisture, evapotranspiration, and day length were also more closely related to daily height growth than to leaf development.

Generally minimum temperature was more closely correlated than maximum temperature with stem height at the soil surface and at 20 and 320 cm. above soil surface and in the shelter for the 1967 and 1968 seasons. The same was true for leaf development in 1967 at soil surface and at 20 and 80 cm. above soil surface.

Correlations between height and minimum temperature at four height levels above the ground were nearly the same in 1967. Soil surface temperature correlation values were greater than those at various heights. The differences were not great at each level in 1968, but minimum shelter temperatures had the greatest values.

Correlation values between mean maximum temperature for 100 minutes and daily leaf and height development were usually only slightly greater than correlation values of daily maximum temperature (not included in table 3).

Mean temperature correlation coefficients were intermediate or above those of maximum and minimum temperatures. Temperature range correlations were usually insignificant.

Soil moisture and evapotranspiration were usually more highly correlated with daily leaf development and stem height at the 0–91 cm. level than at the 0–30 and 0–61 levels.

Correlation coefficients of environmental and dependent variables were usually higher for the season as compared with those for seasonal subdivisions.

Multiple Regression Analyses.—The multiple regression of seven independent environmental variables for predicting stem height is given in tables 4–6. The order in which variables were placed in the regression is shown in the tables by the successive addition

TABLE 3.—*Simple correlation coefficients between daily leaf development, stem height, and independent climatological variables, 1967–68* [1]

Variables	Leaf development		Stem height	
	1967	1968	1967	1968
Temperature at—				
10 cm. below soil surface:				
Maximum	0.4451*	−0.1569	0.7589**	0.6523**
Minimum	.5320**	−.0169	.8355**	.7548**
Mean	.4983*	−.0906	.8147**	.7241**
20 cm. above surface:				
Maximum	.4146*	−.1341	.6348**	.6017**
Minimum	.4781*	.0426	.7053**	.7372**
Mean	.5212*	−.0507	.7644**	.7524**
80 cm. above surface:				
Maximum	.4544*	.0117	.7052**	.7783**
Minimum	.4763*	.0337	.6906**	.7326**
Mean	.5270**	.0253	.7898**	.8304**
160 cm. above surface:				
Maximum	.4896*	−.0747	.7678**	.8045**
Minimum	.4606*	.0421	.7084**	.7456**
Mean	.5068*	−.0209	.7875**	.8262**
320 cm. above surface:				
Maximum	.5731**	−.0629	.5743**	.6625**
Minimum	.4729*	.0434	.7299**	.7465**
Mean	.5635**	−.0090	.7347**	.7375**
Temperature in shelter:				
Maximum	.5572**	−.0811	.6192**	.6420**
Minimum	.4865*	.0789	.7281**	.7811**
Mean	.5409**	−.0002	.7175**	.7383**
Radiation	.0133	−.1255	.1371	.6430**
Soil moisture at indicated distance below soil surface:				
0–30 cm	.0273	.2964	.0705	.3098
0–61 cm	−.0220	.2535	−.0120	.4754*
0–91 cm	−.0685	.2330	−.0930	.5867 *
Evapotranspiration at indicated distance below soil surface:				
0–30 cm	.2775	.0172	.5765**	.5074*
0–61 cm	.4172*	.0235	.6472**	.8039**
0–91 cm	.6106**	−.0065	.7483**	.7958**
Day length	.4214*	−.0603	.8495**	.8673**

[1] Degrees of freedom = 21; correlation coefficient r = 0.413 and 0.526 for 5– (*) and 1– (**) percent levels of significant difference, respectively.

TABLE 4.—*Stepwise multiple regression of kenaf daily system height against 7 independent environmental variables with temperature measured 10 cm. below soil surface, 1967–68*[1]

Degrees of freedom (d.f)	F ratio	Coefficient of multiple correlation squared (R^2)	Standard error of estimate	Constant	Partial regression coefficients of variables[2]						
					X_1	X_2	X_3	X_4	X_5	X_6	X_7
					JULY 4–OCT. 3, 1967						
22-------	-------	0	1.2464	---------	-------	---------	-------	-------	---------	---------	-------
21-------	54.43**	.721614**	.6731	−13.06154	-------	---------	-------	1.19055	---------	---------	-------
20-------	6.24**	.787854**	.6021	−15.36962	0.13010	---------	-------	.70466	---------	---------	-------
19-------	20.75**	.898621**	.4271	−14.49881	.31112	−0.34083	-------	1.55001	---------	---------	-------
18-------	1.02	.904104**	.4267	−14.73707	.30848	− .31596	-------	1.47193	---------	−0.00581	-------
17-------	.19	.905202**	.4366	−13.94441	.29778	− .31237	-------	1.43264	---------	− .00639	0.06669
16-------	.005	.905235**	.4499	−13.84338	.29610	− .30710	-------	1.42816	−0.3850	− .00659	.07080
15-------	.000	.905236**	.4647	−13.87891	.29708	− .30810	0.00003	1.42807	− .03455	− .00649	.06880
					JUNE 25–OCT. 14, 1968						
22-------	--------	0	1.3781	---------	-------	---------	--------	-------	--------	------	-------
21-------	63.73**	.752178**	.7022	−10.98990	-------	---------	--------	1.02302	---------	---------	-------
20-------	4.49*	.797632**	.6502	−14.37005	-------	---------	−.00522	1.45620	---------	---------	-------
19-------	2.72	.822981**	.6239	−14.76503	-------	---------	−.00502	1.40858	---------	.01417	-------
18-------	1.70	.838257**	.6127	−12.47432	-------	−.07153	−.00436	1.62018	---------	.01206	-------
17-------	7.34*	.887060**	.5269	−11.65783	.18808	−.19280	−.00068	1.09174	---------	.02248	-------
16-------	8.11*	.925070**	.4424	−13.19410	.21746	−.36884	−.00392	1.28247	1.37938	.02099	-------
15-------	.14	.925810**	.4546	−12.32415	.20390	−.36299	−.00388	1.26019	1.35349	.02023	.04829

1967 AND 1968											
45	------	0	1.3042	------	------	------	------	------	------	------	------
44	119.83**	.731430**	.6835	−11.74787	------	------	------	1.08624	------	------	------
43	4.78**	.758313**	.6339	−12.69517	------	------	−.00235	1.23002	------	------	------
42	3.38	.776360**	.6384	−10.34561	------	------	−.00232	.99995	------	------	.20537
41	4.60**	.798924**	.6127	−7.85912	------	−.08377	−.00198	1.24435	------	------	.26286
40	8.49**	.834132**	.5634	−10.52659	.15760	−.17765	−.00047	1.15125	------	------	.09487
39	2.12	.842712**	.5556	−11.07215	.18930	−.20806	−.00001	1.15818	------	.00782	.05092
38	2.41	.852129**	.5458	−11.85795	.21576	−.29298	−.00049	1.20146	.59035	.00866	.02162

[1] * and ** = statistically significant at 5- and 1-percent levels, respectively.

[2] X_1 = minimum soil temperature (° F.); X_2 = maximum soil temperature (° F.); X_3 = radiation (langleys); X_4 = day length (hours); X_5 = mean maximum temperatures for 100 min. at 20 cm. above soil surface (° F.); X_6 = soil moisture at 0–30 cm. below soil surface (mm.); X_7 = evapotranspiration at 0–91 cm. below soil surface (mm.).

TABLE 5.—*Stepwise multiple regression of kenaf daily stem height against 7 independent environmental variables with temperature measured 160 cm. above soil surface, 1967–68* [1]

Degrees of freedom (d.f.)	F ratio	Coefficient of multiple correlation squared (R^2)	Standard error of estimate	Constant	Partial regression coefficients of variables[2]						
					X_1	X_2	X_3	X_4	X_5	X_6	X_7
					JULY 4–OCT. 3, 1967						
22	---	0	1.2464	---	---	---	---	---	---	---	---
21	54.43**	.721614**	.6731	−13.06154	---	---	---	1.19055	---	---	---
20	5.44**	.781221**	.6115	−13.01047	0.05642	---	---	.93048	---	---	---
19	2.73	.808979**	.5865	−12.97451	.06607	---	---	.93496	---	−0.01233	---
18	.88	.817738**	.5883	−11.22846	.05721	---	---	.80407	---	−.01391	0.18114
17	.90	.826940**	.5899	−10.50999	.07541	−0.03980	---	.92037	---	−.01807	.25000
16	.10	.828110**	.6060	−10.16661	.06573	−.03716	−0.00080	.94080	---	−.01948	.28467
					JUNE 25–OCT. 14, 1968						
22	---	0	1.3781	---	---	---	---	---	---	---	---
21	63.73**	.752178**	.7022	−10.98990	---	---	---	1.02302	---	---	---
20	4.49**	.797632**	.6502	−14.37005	---	---	−.00522	1.45620	---	---	---
19	2.72	.822981**	.6539	−14.76503	---	---	−.00502	1.40858	---	.01417	---
18	1.28	.834766**	.6193	−12.42643	---	---	−.00443	1.16989	---	.01451	.15892
17	.44	.838956**	.6291	−13.13783	---	---	−.00529	1.20973	0.02129	.01437	.16309
16	1.56	.853332**	.6189	−14.73745	.06557	---	−.00438	.94128	.05359	.01921	.03885
15	.07	.854094**	.6375	−15.04259	.06532	.00224	−.00472	.95658	.05729	.01877	.04250
					1967 AND 1968						
45	---	0	1.3042	---	---	---	---	---	---	---	---
44	119.83**	.731430**	.6835	−11.74787	---	---	---	1.08624	---	---	---

43--------	6.5677*	.767013**	.6440	−11.79851	.04974	---------	---------	.86288	-------	---------	-------
42--------	1.7062	.776110**	.6388	−12.39044	.03852	---------	−.00150	1.00484	-------	---------	-------
41--------	1.1864	.782407**	.6374	−10.90196	.02572	---------	−.00176	.92400	-------	---------	.13896
40--------	.4791	.784982**	.6415	−11.33031	.03530	---------	−.00210	.88925	.01929	---------	.12620
39--------	.0433	.785221**	.6493	−11.36030	.03473	.00147	−.00213	.88397	.01978	---------	.12908
38--------	.0062	.785256**	.6577	−11.33097	.03448	.00150	−.00213	.88519	.01945	−.00046	.13061

[1] * and ** = statistically significant at 5- and 1-percent levels, respectively.

[2] X_1 = minimum temperature at 160 cm. above soil surface (° F.); X_2 = maximum temperature at 160 cm. above soil surface (° F.); X_3 = radiation (langleys); X_4 = day length (hours); X_5 = temperature range at 160 cm. above soil surface (° F.); X_6 = soil moisture at 0–30 cm. below soil surface (mm.); X_7 = evapotranspiration at 0–91 cm. below soil surface (mm.).

TABLE 6.—*Stepwise multiple regression of kenaf daily stem height against 7 independent environmental variables with temperature measured in standard shelter, 1967–68* [1]

Degrees of freedom (d.f.)	F ratio	Coefficient of multiple correlation squared (R^2)	Standard error of estimate	Constant	Partial regression coefficients of variables[2]						
					X_1	X_2	X_3	X_4	X_5	X_6	X_7
					JULY 4–OCT. 3, 1967						
22	-----	0	1.2464	-----	-----	-----	-----	-----	-----	-----	-----
21	54.43**	.721614**	.6731	−13.06154	-----	-----	-----	1.19055	-----	-----	-----
20	3.50	.763165**	.6362	−12.34905	-----	0.04930	-----	.92456	-----	-----	-----
19	2.20	.787815**	.6178	−12.18247	-----	.05904	-----	.91836	-----	−0.01167	-----
18	.94	.798346**	.6188	−10.41109	-----	.04771	-----	.78963	-----	−.01332	0.19986
17	3.31	.831259**	.5825	−3.37444	−0.10685	.09210	-----	.70424	-----	−.02197	.43946
16	.17	.833089**	.5971	−3.52500	−.09867	.07680	−0.00104	.75676	-----	−.02351	.47646
					JUNE 25–OCT. 14, 1968						
22	-----	0	1.3781	-----	-----	-----	-----	-----	-----	-----	-----
21	63.73**	.752178**	.7022	−10.98990	-----	-----	-----	1.02302	-----	-----	-----
20	5.21*	.803446**	.6408	−8.38958	-----	-----	-----	.99154	−0.08279	-----	-----
19	.97	.813023**	.6412	−6.87156	-----	-----	-----	.82405	−.07452	-----	.14350
18	.70	.820041**	.6463	−7.53201	-----	-----	-----	.78870	−.05590	.00865	.16316
17	1.54	.835050**	.6367	−13.14293	-----	-----	−.00497	1.21098	.01186	.01583	.16313
16	.64	.842902**	.6405	−14.24929	-----	.03848	−.00447	1.07444	.02969	.02049	.07879

1967 AND 1968

45	--------	0	1.3042	----------	---------	-------	---------	-------	---------	---------	-------
44	119.83**	.731430**	.6835	−11.74787	---------	-------	---------	1.08624	---------	---------	-------
43	8.7337**	.776770**	.6304	−8.98468	---------	-------	---------	1.01435	−.07064	---------	-------
42	2.6862	.790189**	.6184	−7.10808	---------	-------	---------	.82025	−.06679	---------	.17797
41	1.2437	.796366**	.6166	−6.45283	---------	-------	---------	.81632	−.07654	−.00641	.18841
40	.0408	.796573**	.6239	−6.71908	---------	.00551	---------	.80743	−.07270	−.00606	.17363
39	0	.796573**	.6319	−6.72490	---------	.00550	−.00001	.80787	−.07260	−.00606	.17369

[1] * and ** = statistically significant at 5- and 1-percent levels, respectively.

[2] X_1 = minimum shelter temperature (° F.); X_2 = maximum shelter temperature (° F.); X_3 = radiation (langleys); X_4 = day length (hours); X_5 = shelter temperature range (° F.); X_6 = soil moisture at 0–30 cm. below soil surface (mm.); X_7 = evapotranspiration at 0–91 cm. below soil surface (mm.).

of partial regression coefficients of variables. *F* level values obtained as each variable was added to the analyses reveal the significance of the added variable in accounting for additional variation in the dependent variable.

Comparisons of the analyses with different temperature observations show that R^2 values were highest when soil temperatures were used. In 1967 and 1968, 90 and 92 percent of variability in daily height were identified.

In each analysis of height, day length accounted for the greatest amount of variability and therefore entered the analysis first. When soil temperatures were employed in the analysis, several variables were significantly related to height as shown by significant *F* values (table 4). Generally only one other variable significantly accounted for additional variability in each analysis based on aboveground temperatures, temperature range, radiation, or minimum temperature (tables 5 and 6).

Similar stepwise multiple regression analyses for daily leaf development were calculated, but only the analysis based on shelter temperatures is given (table 7). Only evapotranspiration (soil moisture depletion) significantly accounted for variation in leaf development in 1967.

Observed daily stem height increment (fig. 3) and leaf development stage increment (fig. 4) in 1967 were compared to computed or predicted values using all independent environmental variables for shelter temperatures. The accuracy of prediction is evident from these graphs.

Predicting Stem Yield

A relationship between temperature and leaf development may be revealed by plotting daily leaf development for 1961–69 and the long-term daily mean temperatures against the days of the year (fig. 5). Leaf development responses to temperature during the growing season showed that new leaves were produced at an average rate of from 0.2 of a leaf per day in early May and mid-October to slightly more than 0.6 in midsummer. On very hot days one entire leaf developed in a single day, but growth was very slight when temperatures were below 10° C. (50° F).

Interestingly the rate of development is higher in the fall than in the spring at any given temperature. This relationship is shown in figure 6 for mean temperatures. By extrapolation, leaf development may be estimated for temperatures that are higher than the expected mean temperatures at Glenn Dale.

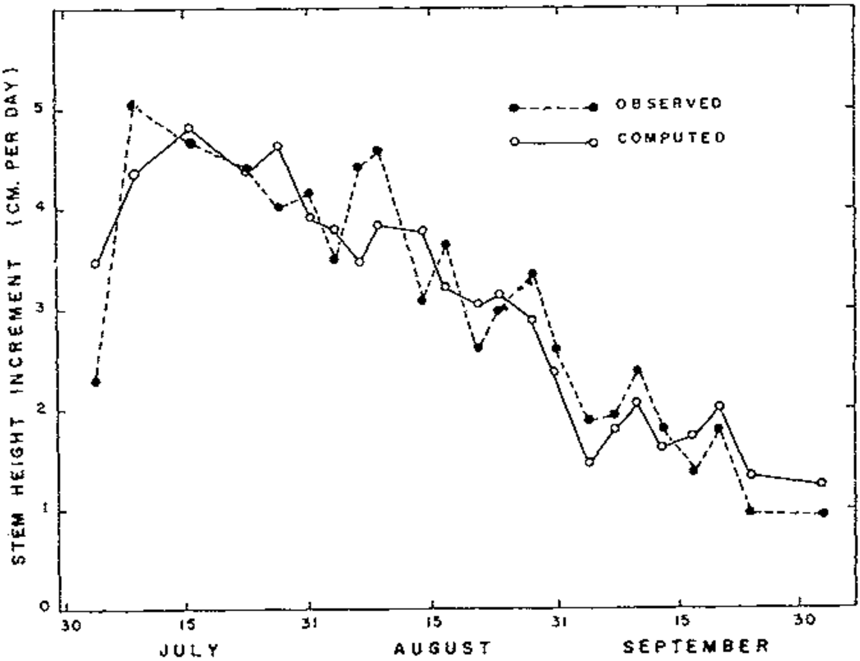

FIGURE 3.—Observed and computed daily stem height increment of kenaf based on shelter temperatures, 1967.

A summation of the mean daily leaf development during the frost-free period at Glenn Dale shows that 75.66 leaves per plant may be expected in an average growing season.

Based on the 1961–67 data (fig. 2) under conditions of adequate soil moisture, stem yield and leaf development were related by the estimated curve $\hat{Y} = -3.116 + 0.24639X$, where $\hat{Y}$ = expected stem yield in metric tons per hectare and X = leaf development. From this equation a yield of 15.5 metric tons of stems per hectare may be expected for plants with 75.66 leaves.

Stem yield estimates for different locations in the United States were made by obtaining monthly mean temperatures from each place and converting these to total leaf development by using figure 6. Accumulated monthly total leaf development was then converted to stem yields using the previous equation. A range of expected accumulated stem yields throughout the growing season for selected locations is given in figure 7. A brief description of this procedure and an illustration of expected yields east of the Rocky Mountains has been published (*8*).

TABLE 7.—*Stepwise multiple regression of kenaf daily leaf development against 7 independent environmental variables with temperature measured in standard shelter, 1967–68* [1]

Degrees of freedom (d.f.)	F ratio	Coefficient of multiple correlation squared (R^2)	Standard error of estimate	Constant	Partial regression coefficients of variables[2]						
					X_1	X_2	X_3	X_4	X_5	X_6	X_7
					JULY 4–OCT. 3, 1967						
22		0	1.4869								
21	12.48**	.3728**	1.2053	3.38831							0.79645
20	1.22	.4091**	1.1988	4.01887						−0.01704	.88575
19	2.19	.4703**	1.1644	6.01766			−0.00487			−.02976	1.03373
18	.571	.4866**	1.1778	4.64734			−.00672		0.06507	−.02840	1.14233
17	.008	.4869**	1.2116	5.31827	−0.00888		−.00685		.06617	−.02921	1.19878
16	.003	.4870**	1.2488	4.97655	−.00989		−.00699	0.03163	.06952	−.00291	1.16974
					JUNE 25–OCT. 14, 1968						
22		0	2.1829								
21	2.092	.0906	2.1307	10.91324					−.17313		
20	.643	.1189	2.1490	7.64481					−.11717	.02701	
19	.303	.1328	2.1874	10.56992				−.22319	−.12038	.02934	
18	.921	.1750	2.1919	7.89168		0.11819		−.81841	−.02398	.04871	
17	.165	.1830	2.2445	4.79680		.15078		−.68841	−.01725	.05131	−.24869
16	.056	.1859	2.3095	8.5071		.15587	.00348	−.99672	−.06147	.04700	−.25982
					1967 AND 1968						
45		0	1.8479								
44	2.546	.0547	1.8170	2.81130		.05999					

43	.976	.0756	1.8175	2.17255	--------	.05464	--------	--------	--------	.01553	--------
42	.584	.0883	1.8264	4.33498	--------	.08542	--------	−.29849	--------	.01657	--------
41	.121	.0910	1.8458	5.71217	--------	.07425	--------	−.38437	--------	.01593	.13035
40	.205	.0957	1.8639	7.82365	−.04290	.09491	--------	−.36178	--------	.01235	.18236
39	.0001	.0957	1.8877	7.86289	−.04356	.09565	.00004	−.36472	--------	.01231	.18197

[1] ** = statistically significant at 1-percent level.

[2] X_1= minimum shelter temperature (° F.); X_2= maximum shelter temperature (° F.); X_3= radiation (langleys); X_4= day length (hours); X_5= shelter temperature range (° F.); X_6= soil moisture at 0–30 cm. below soil surface (mm.); X_7= evapotranspiration at 0–91 cm. below soil surface (mm.).

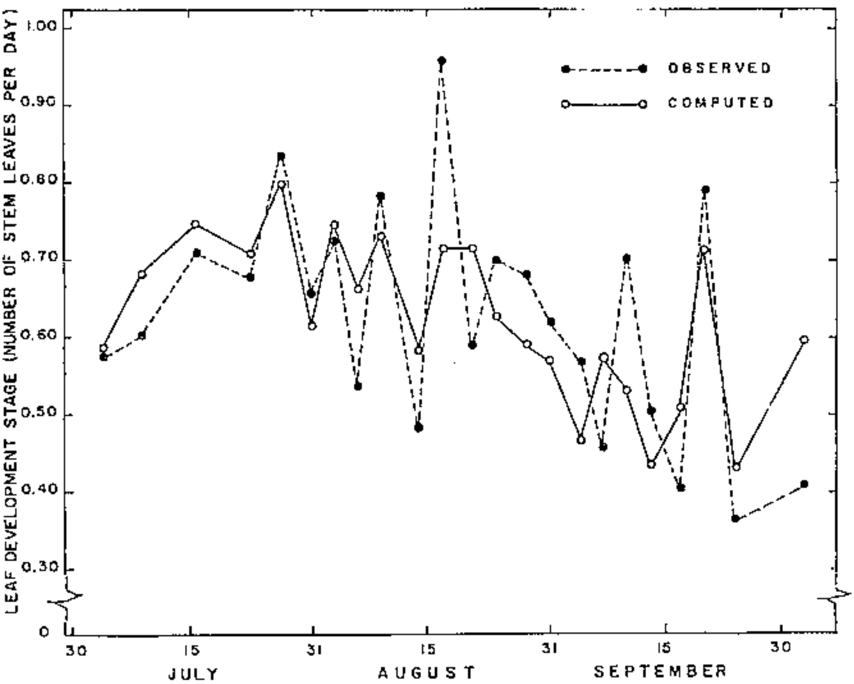

FIGURE 4.—Observed and computed daily leaf development stage increment of kenaf based on shelter temperatures, 1967.

When estimated and observed stem yields were compared for several widely scattered plantings, differences were remarkably minor in many instances. For example, at Rosemount, Minn., and College Station, Tex., estimated stem yields contrasted with observed yields in 1962 were 7.3–6.3 and 35.0–34.1 metric tons per hectare, respectively.

Equations that related stem yield and leaf development in 1968 ($\hat{Y}=-3.434+0.25440X$) and 1969 ($\hat{Y}=-3.695+0.24624X$) were very similar to the 1961–67 equation of $\hat{Y} = -3.116 + 0.24639X$. Thus the previously estimated yields east of the Rocky Mountains may be considered accurate and are expanded now for the entire conterminous United States (fig. 8). Equal yield lines on the map represent successive stem yields of 5 up to 45 metric tons per hectare.

Stem yields may be more than 45 metric tons per hectare in southern Florida, in Texas south of Corpus Christi, and in the Death Valley area. Yields of at least 22–28 metric tons are possible as far north as eastern North Carolina; in most of Alabama, Arkansas, Georgia, Mississippi, Oklahoma, and South Carolina; in practically all of Texas; in the lower elevations of the South-

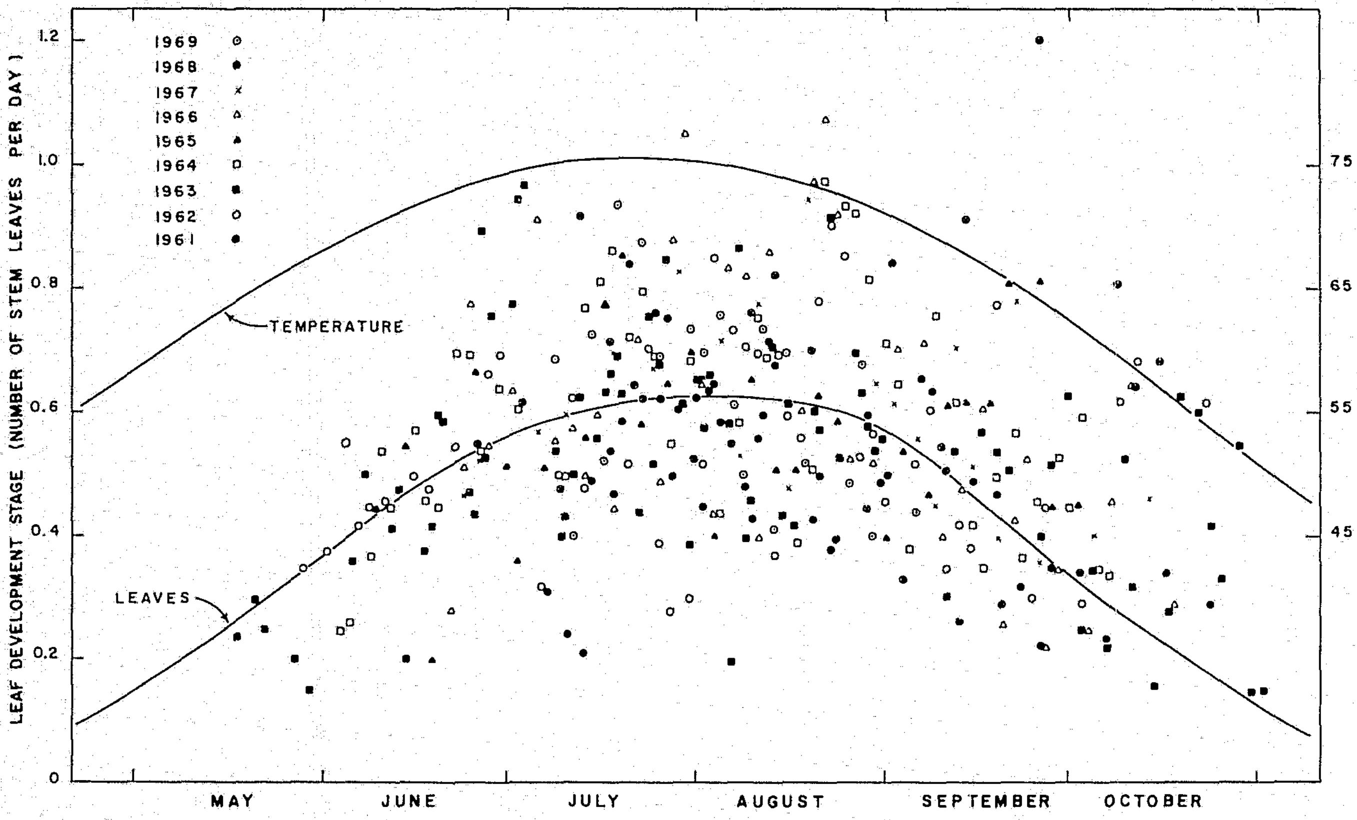

FIGURE 5.—Seasonal leaf development of kenaf and expected mean temperature at Glenn Dale, Md.

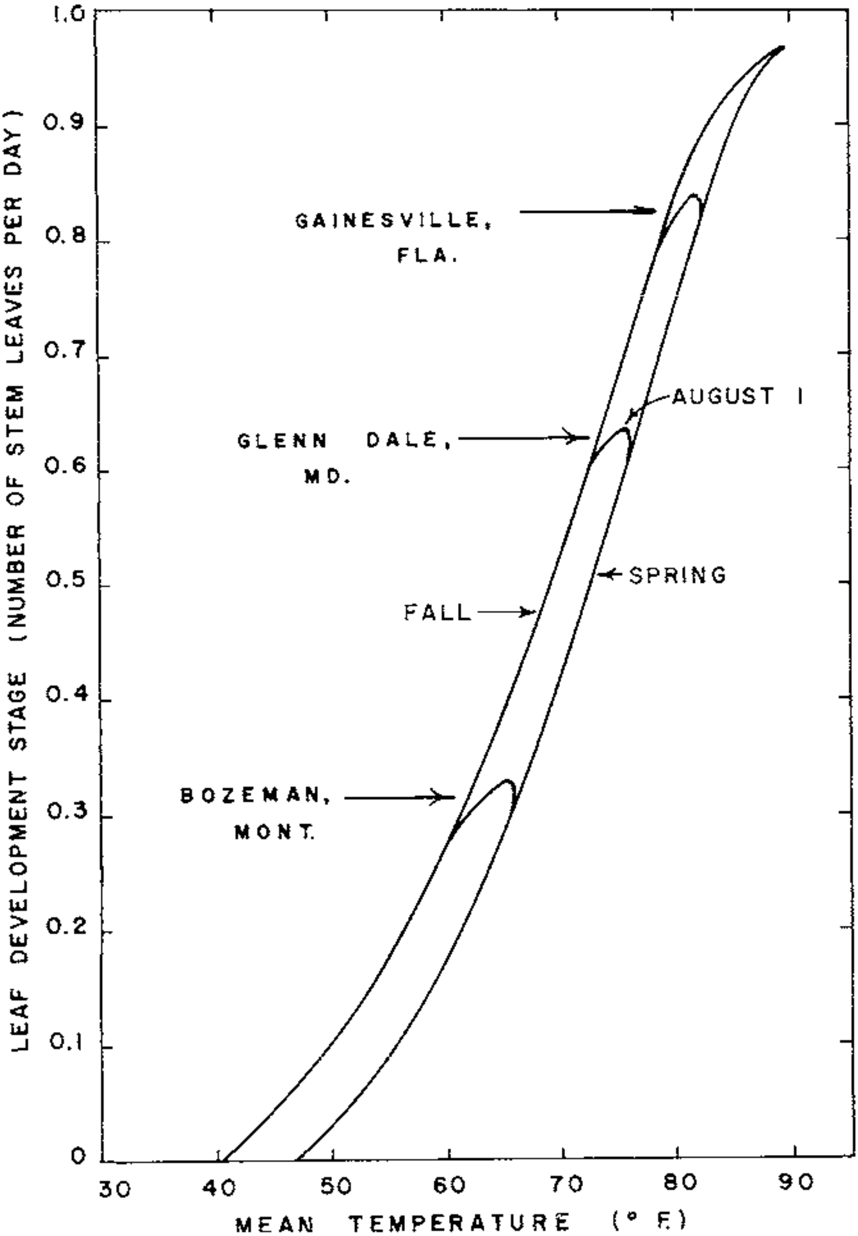

FIGURE 6.—Relationship between kenaf leaf development and mean temperature.

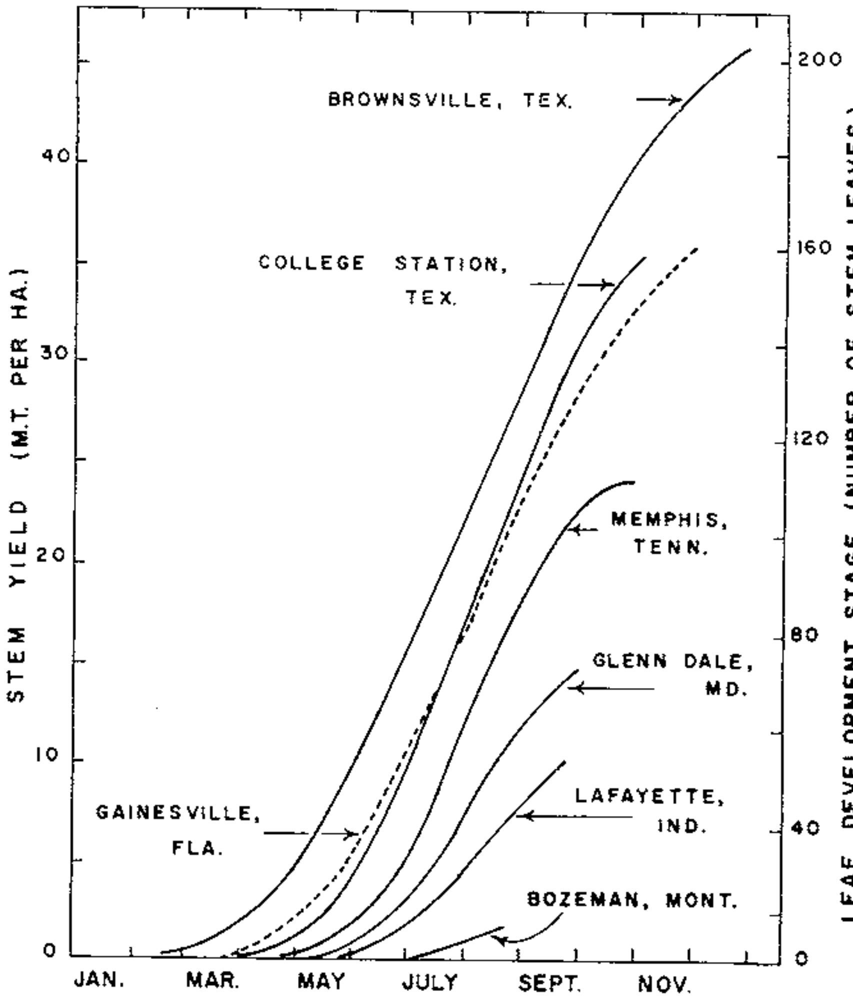

FIGURE 7.—Daily accumulated kenaf stem yields for various locations in the United States.

west; and in most of interior California. In the far northern and in the mountainous regions stem yields will be less than 5 metric tons per hectare but may be from 5 to 10 metric tons near the Snake River in Washington, Oregon, Idaho, and along Lake Champlain in eastern New York.

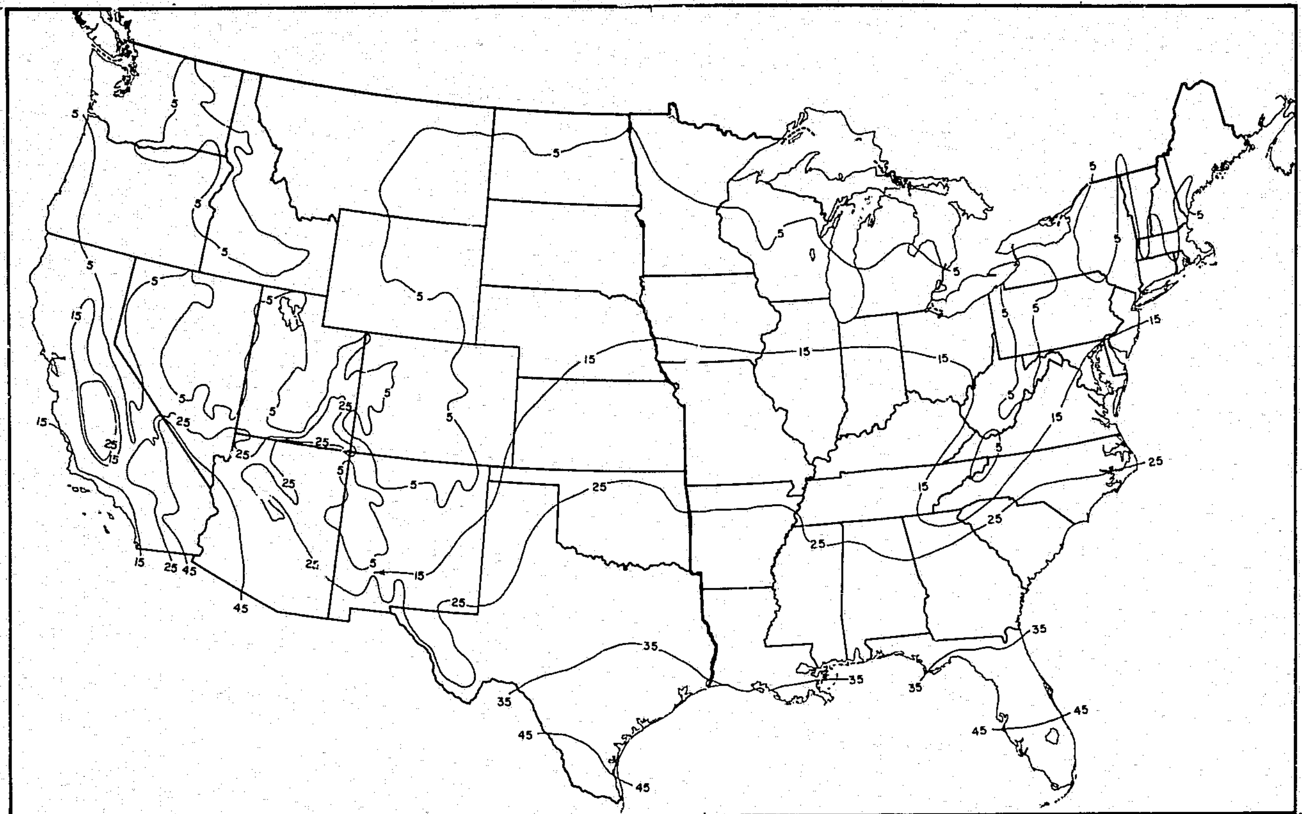

FIGURE 8.—Estimated kenaf stem yields, represented by lines of equal yield, for the United States.

Leaf Yield, Harvest Date, and Growth Correlations

Leaf yields per hectare for 20 harvest dates in 1968 increased from 1,520 to 3,458 kg. (fig. 9). Yields from most of the harvests after July 31 varied from 2,300 to 3,000 kg. In 1969, leaf yields per hectare varied from 2,100 to 2,900 kg. for six harvest dates and two row spacings (fig. 9). Yields were significantly higher in 53-cm. rows than in 36-cm. rows.

Correlations of leaf yield with leaf development stage ($r = 0.17938^{**}$) and stem height ($r = 0.281507^{**}$) were of low magnitude. This is expected because after a certain period older leaves absciss at a rate similar to the production of new leaves. The relationship between leaf development and the lowest leaf node on the main stem is as follows:

$$1968\colon \hat{Y} = -8.771 + 0.7597X \qquad r = 0.9889^{**} \text{ d.f.} = 72$$
$$1969\colon \hat{Y} = -4.565 + 0.6375X \qquad r = 0.9621^{**} \text{ d.f.} = 46$$

where $\hat{Y}$ = lowest leaf node, X = leaf development, r = correlation coefficient, and d.f. = degrees of freedom. At an approximate leaf development of 6–11, leaves began to absciss and at 80, 45–51 leaves had fallen. The rate of leaf fall is 0.64 to 0.76 of the rate of leaf development.

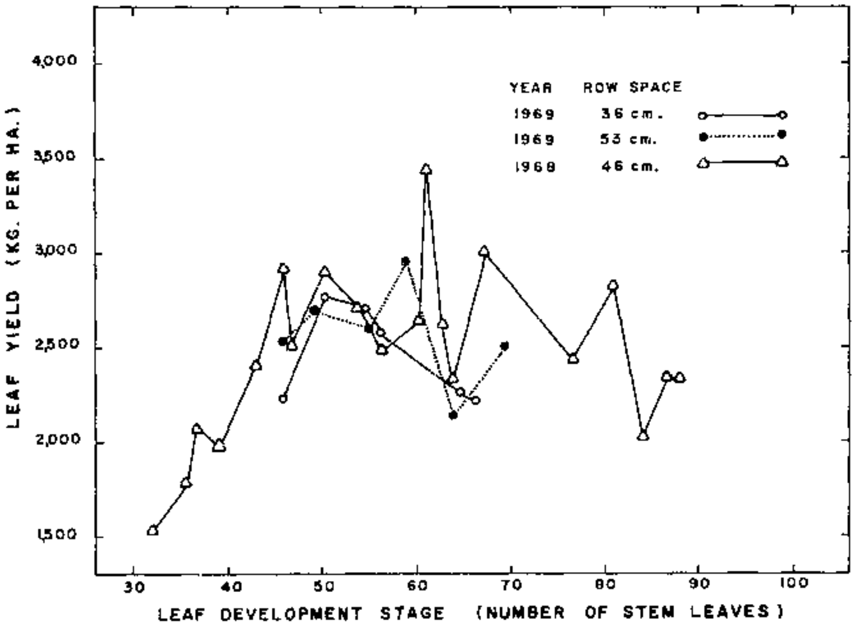

FIGURE 9.—Kenaf leaf yields as related to leaf development stage and row space at Glenn Dale, Md., 1968–69.

DISCUSSION

Kenaf leaf development responses to environmental variables contrast with those for *Tephrosia* (*3*), in which daily height was rarely correlated with temperature. This difference may be explained as follows: The increase in height is more rapid for kenaf than for *Tephrosia*, and thus height of kenaf was probably recorded more accurately. Height of kenaf may be related more closely to temperature as a linear function than height of *Tephrosia*. The reason why leaf development is more closely related to temperature in *Tephrosia* than in kenaf is more difficult to explain. A part of the answer may lie in the relative accuracy of leaf development observations. A few observations of kenaf leaf development were considerably more erratic than would be reasonably expected for the prevailing conditions in 1967 and 1968.

Although daily leaf development was not highly correlated with temperature and other environmental variables, accumulated leaf development was highly negatively correlated with temperature, day length, and evapotranspiration. This may indicate that daily leaf development might have been more closely correlated with these independent variables than was shown if observations had been more accurate or if lag effects of plant response to environment were taken into consideration or both.

Variability in leaf development rates for similar spring and fall temperatures indicates that other environmental variables also affect leaf development. Increase in plant mass through the growing season may modify the general plant environment, and a more fully developed root system may be a factor too. The manner in which leaf development was related to temperature for different seasons (fig. 5) may represent a simple and significant approach to relate more than one environmental variable to leaf development responses.

The 1967 and 1968 leaf development prediction equations indicate that certain environmental variables affect kenaf and that these variables are different in their effect from one year to another and for different sites for recording temperatures. Because of this variation these multiple regression equations were not employed for predicting plant responses to environment.

Also in question are the equations with day length as the principal environmental variable that affected plant height. Unrealistic predictions of height might result for cold northern areas.

The equation $Y = -3.116 + 0.24639X$ provides a good estimate of kenaf stem yield for various leaf development stages. From this equation it is also apparent that stem yield increases at the rate of 246 kg. per hectare for each new leaf developed. Any decrease in length of the growing season because of late planting or early frost may reduce yields from the expected mean yield. The development of one leaf at Glenn Dale requires 5 days on the average in early May and 3 days in early October.

Although maximum leaf yields per hectare reached 3,458 kg., most of the harvests yielded from 2,400 to 2,900 kg. after development of 33 leaves. These yields could be expected in most areas of the United States except in the more northern sections. Leaf yields were reduced after the maximum yield was reached because larger leaves began to absciss in the lower part of plants and newly formed leaves were smaller.

The observed significant correlations were encouraging although they varied from year to year. A satisfactory multiple regression equation to predict kenaf responses to environment can be developed provided the following conditions are met: (1) Use only a trained observer; (2) make daily plant and environmental observations; and (3) vary soil moisture sufficiently to identify its effect.

In addition, several multiple regression analyses should be tried with different sets of environmental variables. Nonsignificant variables should be discarded. Lag effects of environment on plants should be investigated for daily observational data.

The present predictions of kenaf yield for different localities are based on plants grown with adequate fertilizer, soil moisture, and good cultural methods. The estimates appear realistic. However, it would be desirable to discover how a prediction equation can account for soil moisture. When this is finally worked out for one plant species, the approach can then be applied to all species of economic plants. Several to many equations may be required to predict yields of all crops depending on the variability of the environment's effect on each crop's growth.

We have not yet developed an ideal equation to predict kenaf yields in the United States. The species is nearing commercial production. Yield estimates based on a simplified approach for linking crop yield to environment are given so that production forecasts can be made now.

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