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BRAGG SOYBEANS GROWN ON A SOUTHERN COASTAL PLAINS SOIL

I. DRY MATTER DISTRIBUTION, NODAL GROWTH ANALYSIS, AND SAMPLE VARIABILITY

Key Words: plant morphology, Glycine max, plant growth, plant components, plant development

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ABSTRACT

Yields of soybean [Glycine max (L.) Merr.] are affected by the manner in which available resources are partitioned into component plant parts. Little is known about these partitioning processes and much of what has been reported describes indeterminate cultivars or comes from other than field studies. A field investigation was conducted, therefore, on a Goldsboro loamy sand (Aquic Paleudult) to characterize in detail the growth and development of a determinate

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soybean cultivar 'Bragg'. Soybean were grown in well watered field plots in four replications from each of which 4 nested samples of 0.3 m^2 each were combined at each sampling. Leaf area, dry matter production, internode length, and sample variability were determined nodally at 10- to 14-day intervals from 7 July to 17 October. Plant components at each node were separated into stems, leaf blades, pods, and petioles. Primary and secondary branches were combined in the petiole fraction.

Maximum above ground plant dry weight achieved was 1027 g/m^2 and maximum combined nodal dry weight was 92 g/m^2 (at node 8), both occurring at the R7 growth stage. Canopy dry weight distribution over time was unique for each plant part. Growth analyses showed that RGR, NAR, LAR, and LWR declined with plant age at a rate that could be described with either linear or exponential models. A maximum CGR of 16.24 $g/m^2/day$ occurred at mid-podfill and declined thereafter due to maturity. Leaf area per node peaked between nodes 7 and 12, decreasing uniformly toward the top of the canopy. Maximum nodal LAI was 0.79 at node 7 on 31 August.

Distribution of dry weight among parts varied with plant age and node position. Maximum dry weights of stems (276 g/m^2), petioles (253 g/m^2), and leaves (263 g/m^2) were found during mid-podfill. During mid-August, the dry weights of the stems, petioles, and leaves were similar and approximately 250 g/m^2. Stem dry weights had the lowest coefficients of variation of all plant fractions once maximum dry weight was achieved. Internode length varied along the stem with the maximum at node 12. By bloom, expansion of the internodes lower than 12 had ceased; expansion of the eight higher internodes ceased three weeks later. During vegetative growth, the ratio of stem internodal dry weight to internodal length had peak values at the lowest and highest internodes. During reproductive growth, the ratio decreased linearly with internode number. Coefficients of variation (CV) for the combined weight of plant parts, and for stems, petioles, leaves, and pods were relatively constant during the season and were 24.8, 23.4, 38.2, 25.5, and 26.8%, respectively. The CV's for the combined weight of plant parts were somewhat higher at the lowest and uppermost nodes. This variability resulted from the abscission of petioles and leaves in the lower nodes and the initiation of leaves, petioles, and pods in the upper nodes where rapid growth and development was occurring. Time from node initiation to achievement of lowest stable CV was determined for each node and plant part. Plant node position and morphological part with the lowest CV was identified for each sampling date (and growth stage).

INTRODUCTION

During the growing season, soybean [*Glycine max*. (L.) Merr.] partitions available assimilates into its component plant parts. Both quantity of assimilates partitioned and the direction in which they are partitioned play a large role in determining growth, plant development, and yield. Furthermore, while it is commonly recognized that many physiological and morphological parameters vary with position on the plant and with time of sampling, little is known about the morphological and chronological dependence of sample variability[7]. The morphology of the soybean was reviewed by Carlson[2] and Shibles et al.[19]; however, there is no information available on nodal growth rates, dry weight accumulation, and sample variability of individual plant parts. An understanding of these sources of variation is needed in the formulation of accurate plant growth models[10,24].

Many researchers have studied dry matter accumulation by field-grown soybeans[5,7,9,12,13,14,18,22,23]. While determinate soybeans account for a significant proportion of the U.S. and South American soybean acreage, most of the existing data deal with indeterminate cultivars. These studies have provided descriptions of seasonal growth patterns from whole plant data, although few provide sufficiently detailed observations for use with crop models dependent on descriptions of growth and nutrient uptake by the various plant parts. In addition, little or no information has been published on the variability which could be expected from field sampling of whole plants and plant parts in a relatively uniform field.

A number of experimental problems could benefit from a knowledge of time-dependent morphological variation. They include: determinations of nutrient concentrations of specific plant parts and translocation of nutrients between parts[15,17,25]; selection of internodal position for placement of automated growth monitoring devices, e.g. linear variable differential transformers (LVDT) for stem diameter measurements[20]; and selection of pod position for study of seed development rates[4,5,11].

A study was established on a southeastern U.S. Coastal Plain soil to evaluate by nodes the seasonal growth and development of a determinate soybean cultivar grown under field conditions. The manner in which these soybeans partitioned dry matter into their component parts and the variability of samples was examined. The length of time after node initiation when one would obtain the lowest CV for each node and plant part was identified, and the nodal position and plant part with the lowest CV were identified for each date of sampling and its respective growth stage. Similar analysis of nutrient concentrations and uptake will be presented in succeeding papers of which this is the first in a series.

MATERIALS AND METHODS

This field study was conducted at the new Pee Dee Experiment Station near Florence, South Carolina in 1979. The soil at the study site was a uniformly sloping (0.75%) Goldsboro loamy sand (Aquic Paleudult, fine, loamy, siliceous, thermic). The experimental site has been described by Doty and Parsons[3] and was equipped with a combination drainage-subirrigation system with tile lines on 16-m spacing. Soil water status was monitored with tensiometers at 15-, 30-, 46-, 61-, 76-, 91-, 122-, and 152-cm depths in the rows and row-middles (furrows) at four locations in the field with four tensiometer banks per location. A daily water balance was computed for the field using measurements of the water pumped into the tile lines, rainfall, and pan evaporation.

The soybean cultivar grown was 'Bragg', which is a determinate cultivar in maturity group VII. Fertilization was according to soil test recommendations. Chemical weed control was by preplant incorporation of Treflan[26/] (*α*, *α*, *α*-trifluro-2,6-dinitro-N,N-dipropyl-*p* toluidine) at 1.75 L of material/ha and application at planting of Lasso (3-(3,4-dichlorophenyl)-1,1-dimethyl urea) at 4.94 L/ha of material. Subsequent weed control was maintained by timely cultivation twice during the growing season. Insect control was achieved by aerial application of Lannate (S-methyl-N-[(methylcarbamoyl)oxy] thioacetimidate) at 1.75 L/ha of material at midseason. The soybeans were conventionally planted to a stand of 220,000 plants/ha on 23 May in rows 1-m wide and 75-m long in a field of approximately 1 ha. The experimental design was a nested factorial at four locations with four replications at each location (for a total of 16 individual samples, each 0.30 m^2 in size).

The plants in a 0.30 m^2 area were counted and severed at the soil surface on a total of 10 sampling dates at 10 to 14 day intervals from 7 July to 17 October. Four representative plants were chosen and brought to the laboratory where they were separated by nodes into component parts of stems (main stems only), leaves (leaf blades only), petioles (including branch stems at that node), and pods. Lateral, primary and secondary branches emanating from a given main stem node position were included in the fraction called petioles. This sectioning scheme was employed to accommodate the conceptual requirements of a nodally segmented mineral nutrient uptake model developed by the senior author for soybean. The nodes were assigned numbers and the growth stages were identified according to the conventions and nomenclature presented by Fehr et al.[7]. Each numbered internodal main stem segment was made up of the identified node ($Node_n$) and the internodal tissue between it and the next lowest numbered node ($Node_{n-1}$). Internode lengths were recorded and weight per unit length was calculated for each internode. After leaf area was determined with a LI-3100 leaf area meter, plant parts were oven dried at 60C, weighed, and ground for nutrient analysis. Plant height and weight of dropped leaves and true petioles were determined throughout the season.

An analysis of variance was performed on the dry weights by considering sampling locations in the field, replications, and sampling dates as the main sources of variation. Interaction terms, location x replication and location x date x replication, were used to test the location and time integrated sources of variation, respectively. Growth and development were characterized for the individual plant parts at the various nodes and on the various sampling dates as well as for the whole plant. Partitioning of the assimilates was characterized by computing partitioning coefficients (component weight/combined weight of plant parts) and traditional growth analyses parameters[6,16]. Dependent variables were regressed over time and nodal position for development of statistical response surfaces. Surfaces describing accumulation of real entities (e.g. weight, area, length) were forced to zero in the absence of data (as would be the case for upper nodal positions early in the season), whereas, deduced parameters (e.g. CV's) were simply extrapolated over all nodal positions even in the absence of data.

Mean values of crop growth rate (CGR), relative growth rate (RGR), net assimilation rate (NAR), leaf area ratio (LAR), specific leaf area (SLA), and leaf weight ratio (LWR), were calculated from dry weights and leaf areas obtained on the ten sampling dates.

RESULTS AND DISCUSSION

There was a close relationship between the cumulative screened-pan evaporation and cumulative water applied during the season. Seasonal rainfall, pan evaporation, water pumped and total water applied (rainfall, plus water pumped) were 65.5 cm, 60.5 cm, 14.2 cm, and 79.7 cm of water, respectively. On 4 and 5 September, a total of 28 cm of rainfall fell following which the water table remained elevated until the end of the growing season. Meteorological data are summarized in Figure 1.

A brief and mild stress period occurred between 10 August and 4 September as defined by precipitation deficit. During this period, cumulative rainfall of 3.8 cm was considerably below screened-pan evaporation of 11.8 cm. However, tensiometer data indicated that

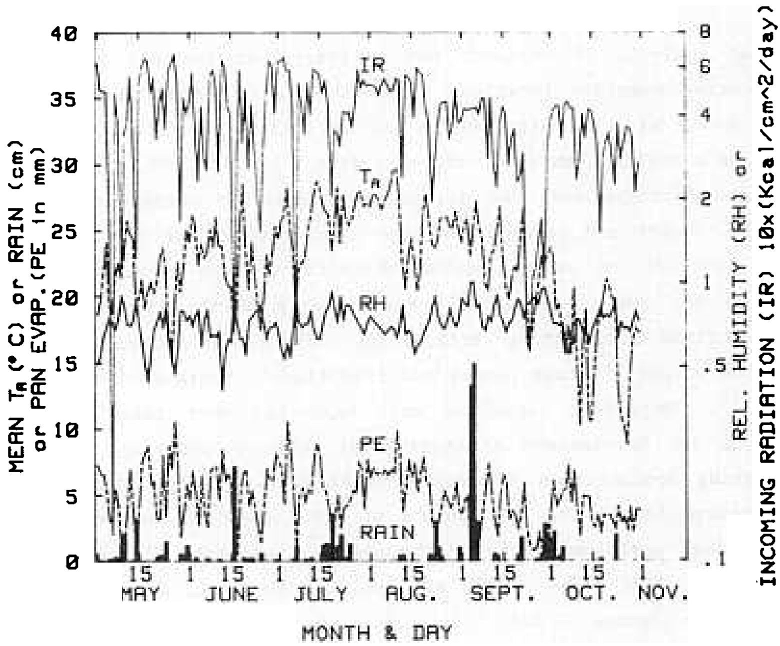


Fig. 1. Climatic data for the 1979 growing season for Florence, S.C. including: mean daily T_A (°C), rainfall (cm), pan evaporation (mm), R.H. (decimal fraction), and incoming radiation (10 x [Kcalcm^{-2}day^{-1}]).

soybean roots were extracting stored water from the lower profile, particularly near the fringe of a water table whose level decreased from a depth of 88 to 127 cm during this period. The volume of extraction during this period resulting in the decreased water table depth was sufficient to offset the 8 cm precipitation deficit. Due to presence of a water table (which is common in Coastal Plain soils) and the close relationship between water applied and screened pan evaporation, these soybeans were without significant water stress during the growing season.

Whole-Plant Growth and Development

Statistical analyses of the whole-plant dry weights indicated that variation due to location in the field and date were highly significant, but the location x date interaction was nonsignificant. This indicates that while each of the four sampling locations in the field had identifiable differences, the entire field was uniformly affected by time-integrated sources of variation (e.g. by plant development, rainfall, and temperature). Furthermore, each location was relatively uniform in its immediate sampling area.

Whole-plant dry weights, heights, morphological growth stages and leaf area indexes (LAI) verify the determinate characteristic of Bragg soybeans (Fig. 2). Curve shapes are similar to those previously reported for determinate soybeans[5,18,21] with characteristic flattening of slopes following onset of the reproductive stage. Growth indices increased to a maximum during mid-to-late reproductive growth. Maximum plant height of 119 cm and maximum LAI of 6.4 occurred on 31 August during the R5 growth stage. Maximum dry weight of 1027 g/m^2 was achieved on 9 October at the R7 growth stage. The abrupt decrease in plant height in early September was due to slight lodging as a result of the 28 cm of rainfall.

Some vegetative growth continued briefly after flower initiation. By bloom (growth stage R1) plants had reached 79% of maximum height, but had produced only 37% of maximum plant dry weight, 44% of maximum vegetative dry weight, and only 48% of maximum LAI. Egli and Leggett[5] found that by bloom the determinate soybean, D66-5566, had reached 84%

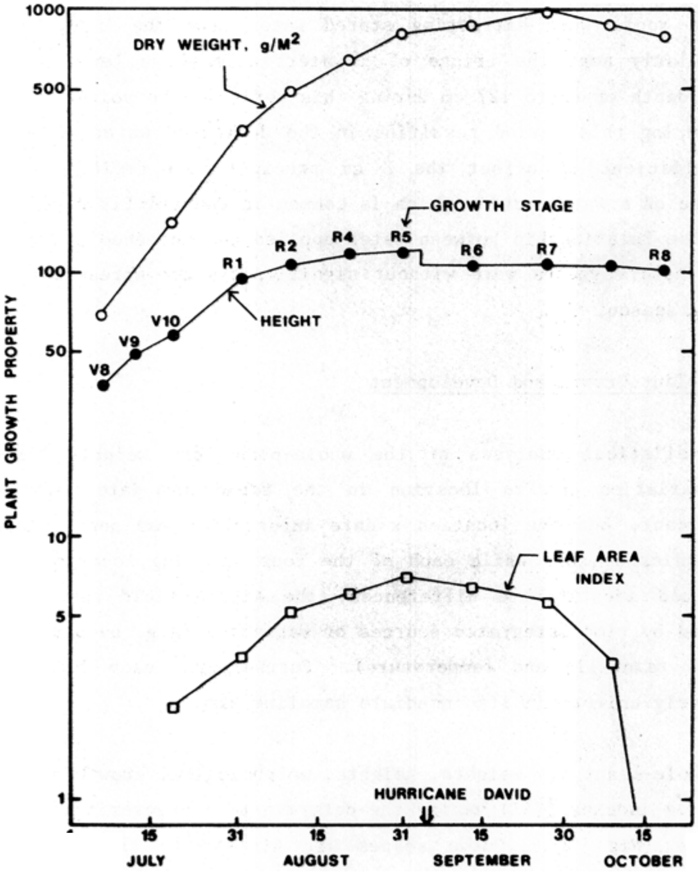


Fig. 2 Seasonal accumulation of total above ground plant dry weight height in cm, and leaf area index for Bragg soybean.

of its maximum height and had produced 78% of its maximum vegetative material. Comparison of these two cultivars demonstrates that dry weight accumulation with respect to growth stage varies among determinate cultivars.

Seasonal Whole-Plant Dry Weight by Plant Part

The weights of leaves, stems, petioles, and pods varied with plant age (Fig. 3). The top curve represents the total above ground

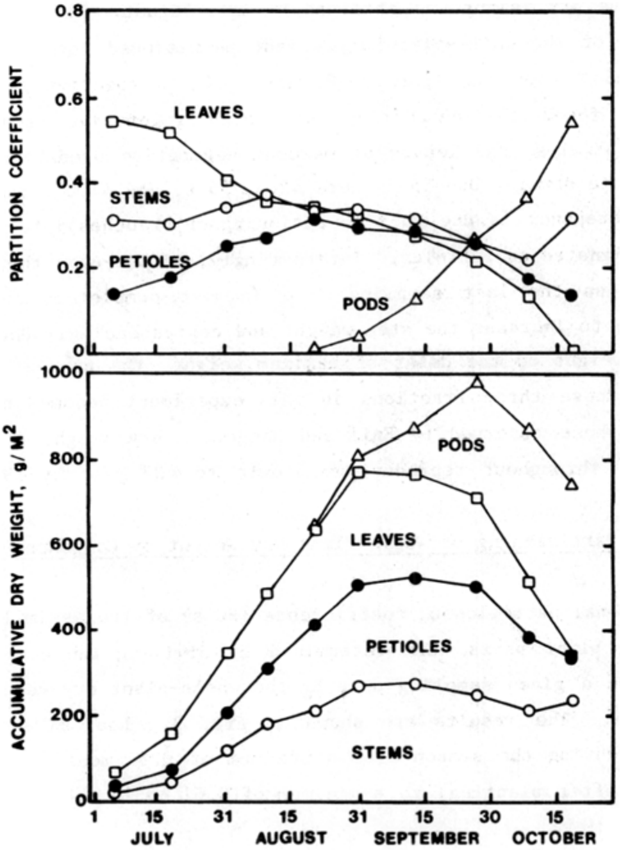


Fig 3. Whole-plant partition coefficients and seasonal dry matter accumulation of Bragg soybean for the component weights of stems, petioles, leaves, and pods.

plant dry weight, and the differences between curves represents the dry weights of a given component. The percentage of each individual component's maximum accumulated dry weight already on the plant at bloom were 43, 35, and 54% for stems, petioles, and leaves, respectively. The dry weights of the stems and plant heights changed little after 31 August, reaching a maximum of 276 g/m^2 on 3 September with a corresponding plant height of 119.3 cm. Petiole and leaf dry weight increased to maximums of 253 and 263 g/m^2 on 27 September and 31 August, respectively. The decrease in petiole and leaf dry weight after these dates are attributed primarily to abscission. The maximum vegetative dry weight was obtained by late August. At this time, the fraction of the whole-plant dry weight partitioned into stems, petioles, and leaves was 35.2, 30.8, and 34.0%, respectively. Egli and Leggett[5] found the percentages of total vegetative production in stems, petioles, and leaves at maximum vegetative production for the determinate strain, D66-5566, were 42.5, 16.6, and 41.0%, respectively. This discrepancy is due to the sectioning of branches into the component designated as petioles. Interestingly, if one uses the weight of petioles on the last sampling date (almost completely composed of branches) to increase the stem weight and correspondingly decrease the petiole weight on the dates of maximum weight, the percent accumulation of these three fractions in this experiment becomes nearly the same as those observed by Egli and Leggett. Dry weight of the pods increased throughout reproductive growth to 403 g/m^2 by 19 October.

Seasonal Partitioning of Whole-Plant Dry Weight by Component

Seasonal partitioning coefficients (PC's) of the assimilates into component plant parts were determined by dividing the component dry weights on a given sampling date by the whole-plant dry weight on the same date. The results are shown in Fig. 3. Leaf PC's declined linearly during the season from a maximum of 0.54 measured on 6 July (44 days after planting) to a minimum of 0.01 on 19 October (149 days after planting).

Petiole PC's increased to a maximum of 0.32 during mid-August which corresponded to pod initiation, then decreased to 0.13 on 17 October. The decrease in the leaf and petiole partitioning coefficients during late September and October can be attributed primarily to abscission of these components from the plant. The petiole PC's did not decrease to as low a value as the leaves because the first order branches remained on the plant during senesence. Since we would expect the PC and accumulated dry weight of true petioles to approach zero by the last sampling date, the difference between the recorded weight (or the recorded coefficient) and zero gives a reasonable estimate of the final contribution of the branches to whole plant dry matter accumulation. If examined by nodal position, these parameters also show that branching was restricted mainly to nodes 2 through 10.

Stem PC's remained fairly constant and averaged 0.31 during the season. Their decline during September and October was due to the greater proportion of fruit to whole plant dry weight. The increase on 19 October was due to petiole and leaf abscission. Pod PC's increased throughout reproductive growth to a maximum of 0.54 on 19 October.

Seasonal Combined Weight of Plant Parts by Nodes

The seasonal distribution of the combined weight of plant parts by nodes shows the influence of node position and plant age (Fig. 4). After mid-July, the combined weights generally increased to a maximum on 27 September then decreased. This decrease in dry weight after 27 September is due to the abscission of leaves and true petioles during senescence.

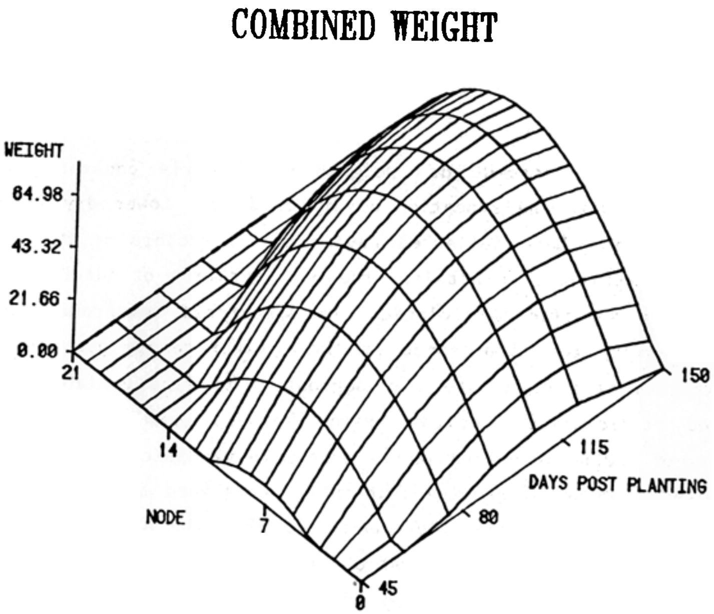


Fig. 4. Combined weight (in grams per square meter) of plant parts (internode stem segment, petioles plus branches, leaf blades, and pods) at each nodal position as affected by time in days after planting for Bragg soybean.

Substantial first and second order branching commonly occurred near nodes 4 and 8. Growth of these branches continued through the vegetative and briefly into the reproductive stages. After bloom (1 Aug.) the maximum combined nodal dry weight in the canopy occurred at node 8 (92 g/m^2 on 27 Sept) with secondary peaks at nodes 4 and 12 at the R7 growth stage. Above node 12, combined nodal dry weight declined linearly with node number. At any given node, the changes in dry weight with time suggest that growth rates vary within the canopy during the season. Mathematical relationships for calculation of the node x date x weight response surface are presented in Table 1.

Seasonal Component Dry Weight by Nodes

Seasonal dry weights of the four plant components by nodes are presented in Fig. 5a-5d and Table 1. Again, each plant part had characteristic growth patterns dependent upon growth rates, development, date, nodal position, abscission, and senescence. Dry weights generally reached a maximum during August for the stems, during September for the petioles and leaves, and at the end of the season for the pods.

Actual stem segment dry weights were nearly constant through internode 12 with the exception of internode 3. Lower dry weight at internode 3 may have reflected environmental factors at the time of internode extension. Otherwise, the configuration of internode 3 may point to a specific morphological or structural requirement of the stem necessary for maintenance of the upright canopy geometry. The dry weights of more mature stem segments were less variable and increased at relatively uniform rates between sampling dates. Dry weights of the petioles and leaves were more variable, particularly at the lower 5 nodes, suggesting that these parts were more responsive to environmental and ontogenetic conditions than the stems. Abscission of leaves and petioles was first observed at the lower nodes around 1 August and throughout the canopy from late September through October. Peaks of actual maximum dry weight of petioles (and to a lesser extent leaves) were found at nodes 4, 8, and 12. These peaks were largely associated with first order branching originating in these nodes.

TABLE 1

Mathematical and statistical description of surface response relationships for the named parameters using the equation form $Y = a + b\,(\text{node}) + c\,(\text{node})^2 + d\,(\text{date}) + e\,(\text{date})^2 + f\,(\text{node})(\text{date})$. Factors not significant at the 0.1 level of probability are deleted and indicated as "NS".

Parameter (Y)	a	b	c	d	e	f	Combined R^2
1 Combined wt.	-95.540	7.215	-0.596	2.011	-0.009	0.035	0.83
2 Stem wt.	-28.418	0.919	-0.110	0.762	-0.003	0.004	0.87
3 Petiole(+branches)wt.	-42.768	1.724	-0.136	0.985	-0.004	NS	0.65
4 Leaf blades wt.	-37.898	2.740	-0.185	0.857	-0.005	0.010	0.63
5 Pod wt.	-42.353	5.173	-0.246	NS	NS	NS	0.72
6 Stem PC	0.645	-0.084	0.003	0.004	NS	NS	0.68
7 Petiole(+branches)PC	-0.339	NS	NS	0.013	-0.0001	-0.001	0.52
8 Leaf blade PC	0.397	0.056	NS	-0.004	NS	-0.0004	0.84
9 Pod PC	1.017	-0.056	-0.0004	-0.020	0.00009	0.0007	0.97
10 NLAI	-1.382	0.085	-0.005	0.030	-0.0002	0.0001	0.72
11 Stem internode length	-7.010	1.152	-0.065	0.147	-0.0007	0.002	0.67
12 Internode wt./length	0.612	-0.331	NS	0.081	-0.0003	NS	0.83
13 CV of combined wt.	61.903	NS	0.304	NS	0.005	-0.077	0.14
14 CV of stems	112.448	NS	0.203	-1.990	0.010	-0.047	0.19
15 CV of petioles	299.573	-9.134	0.788	-3.525	0.020	-0.097	0.21
16 CV of leaf blades	400.220	NS	0.766	-6.496	0.039	-0.102	0.26
17 CV of pods	220.513	-19.681	0.870	NS	NS	NS	0.22

STEMS

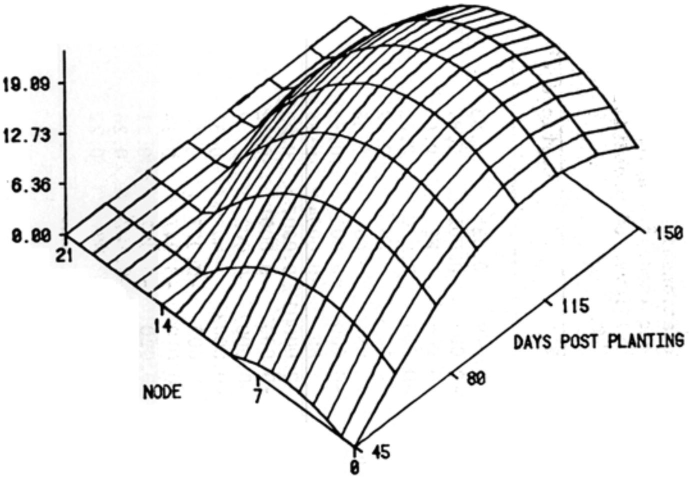
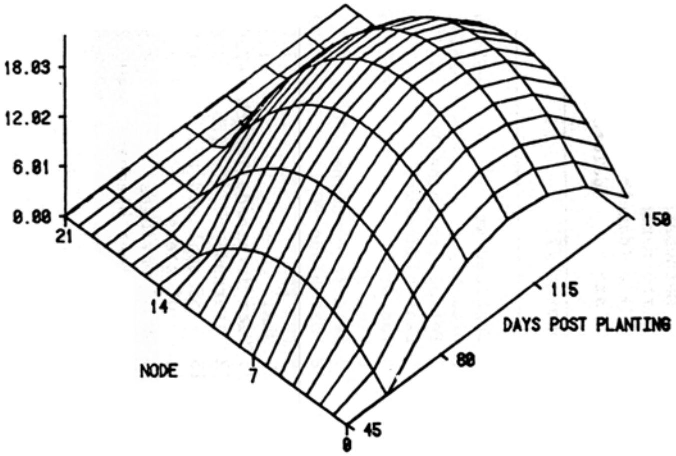


Fig. 5a Weight (in grams per square meter) in internode mainstem segments as affected by nodal position and by time in days after planting for Bragg soybean.

PETIOLES (+BRANCHES)



ig. 5b. Weight (in grams per square meter) of petioles (plus branches) at each nodal position as affected by time in days after planting for Bragg soybean.

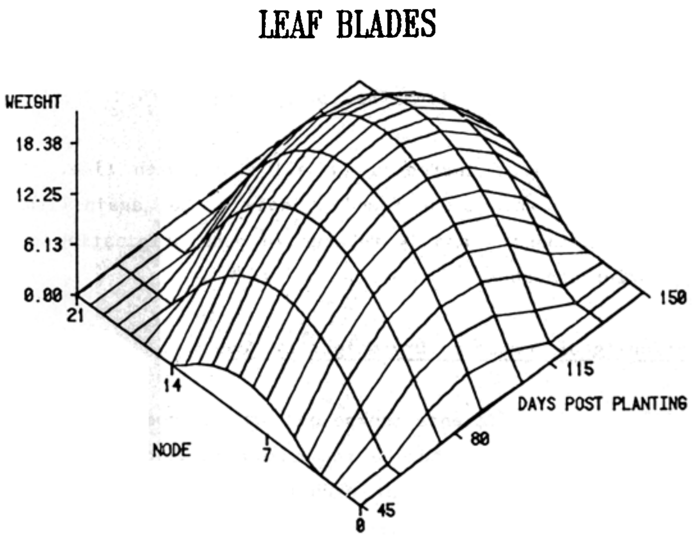

LEAF BLADES

Fig 5c Weight (in grams per square meter) of leaf blades at each nodal position as affected by time in days after planting for Bragg soybean.

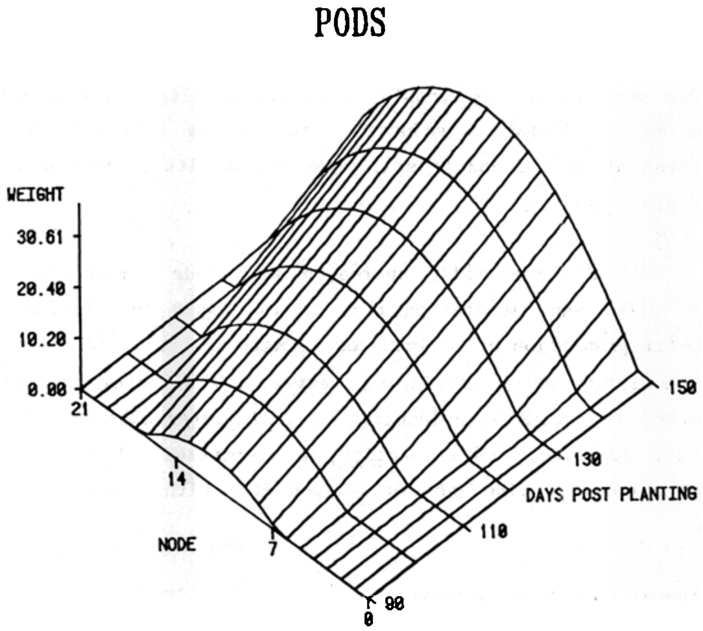

PODS

Fig. Weight (in grams per square meter) of pods at each nodal position as affected by time in days after planting for Bragg soybean.

Above node 12 little or no branching occurred and growth at a given node position was primarily affected by time.

Pod dry weight increased at all nodes with time. The actual maximum pod dry weight was found at node 8, but again with secondary peaks around nodes 4 and 14 related to pods originating on first or second order branches.

Partitioning of Component Dry Weight by Node

Partition coefficients (component dry wt./combined plant part dry wt.) were computed to describe the manner in which the Bragg soybeans partitioned the dry weight at each node into nodal component parts. The influence of node position, plant age, and component part on values of the partition coefficient (PC) are presented in Fig. 6a-6d and Table 1. The highest actual stem PC was at node 1, and the lowest was at the top of the canopy. Secondary peaks observed at node 8 on 6 July, at node 6 on 1 August and 21 August, and at node 5 on 27 September are correspondingly associated with lower PC's for the petioles and leaves at these points. Stem and petiole PC's above the first few nodes were relatively constant, declining slightly with node number and date. During reproductive growth, the actual petiole PC was highest at node 3 and generally decreased with increased node number and plant age.

Leaf PC's generally increased with node number, but decreased with plant age, indicating that in the upper (developing) canopy a greater proportion of assimilates is utilized for production of leaves, particularly newly developing leaves. With onset of reproductive growth, the relative proportion of assimilates allocated to leaf dry weight declines, and allocation of assimilates is diverted to pods with a corresponding increase in pod PC's with node number and plant age.

Seasonal Leaf Area by Nodes

The relationships between nodal leaf area index (NLAI), node number and date are presented in Fig. 7 and Table 1. As with leaf dry

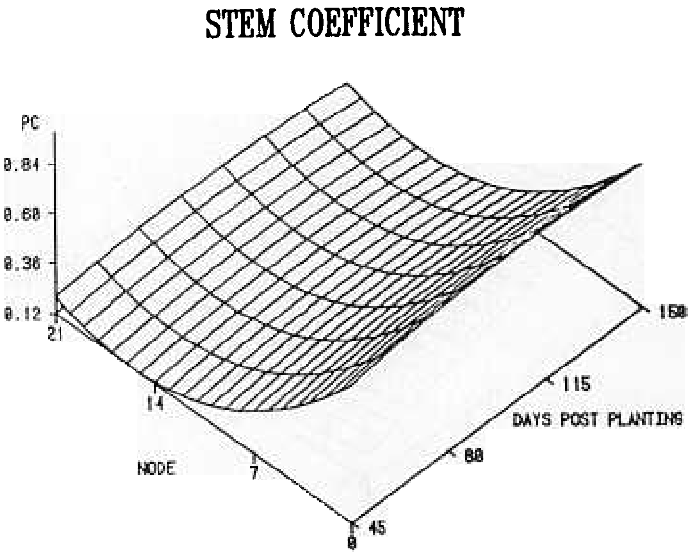

STEM COEFFICIENT

Fig. 6a. Partition coefficient of stems at each nodal position as affected by time in days after planting for Bragg soybean.

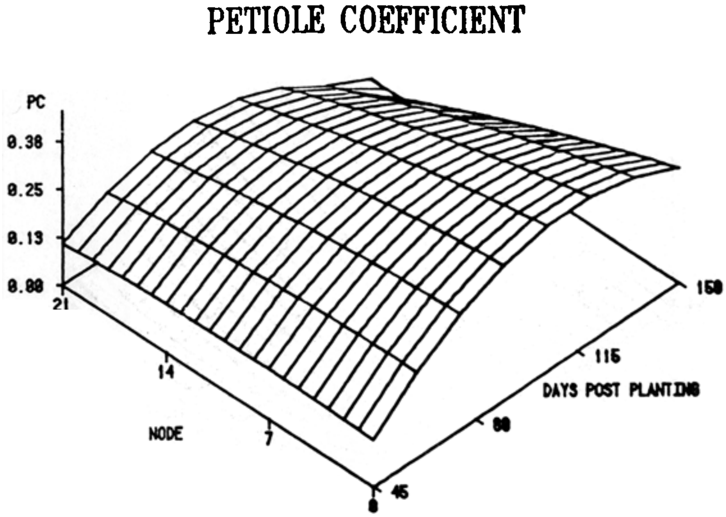

PETIOLE COEFFICIENT

Fig. 6b. Partition coefficient of petioles (+ branches) at each nodal position as affected by time in days after planting for Bragg soybean.

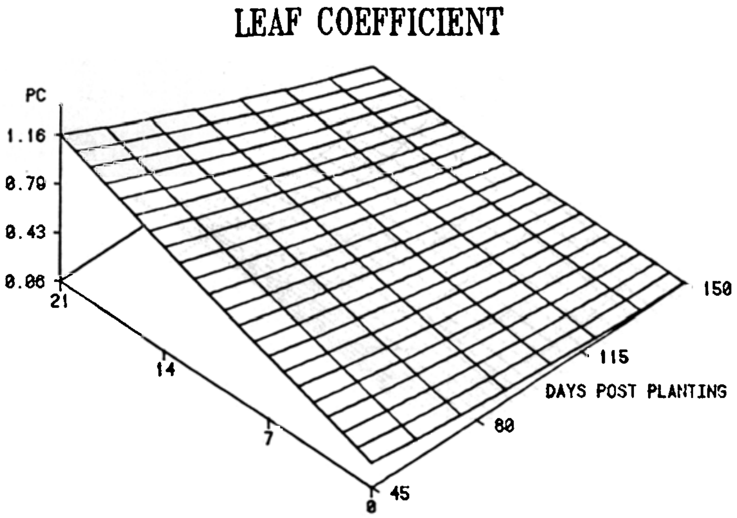


Fig. 6c Partition coefficient of leaf blades at each nodal position as affected by time in days after planting for Bragg soybean.

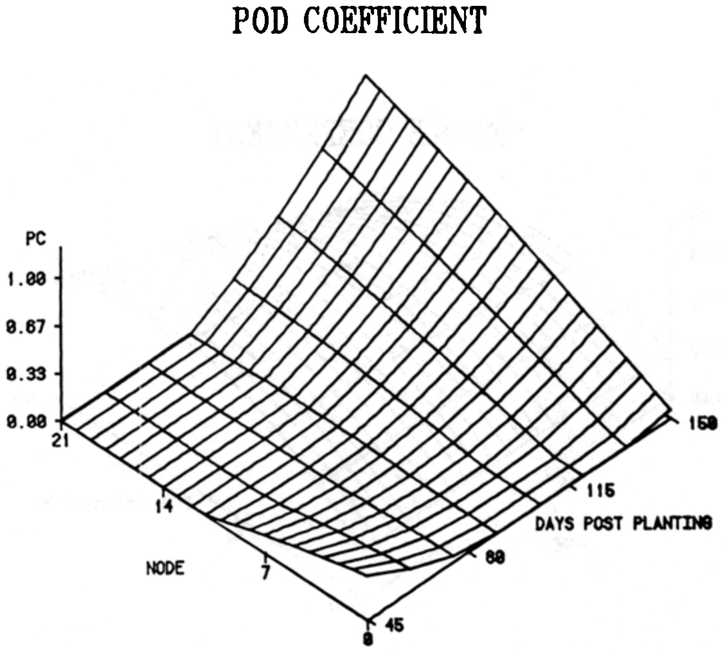


Fig. 6d Partition coefficient of pods at each nodal position as affected by time in days after for Bragg soybean.

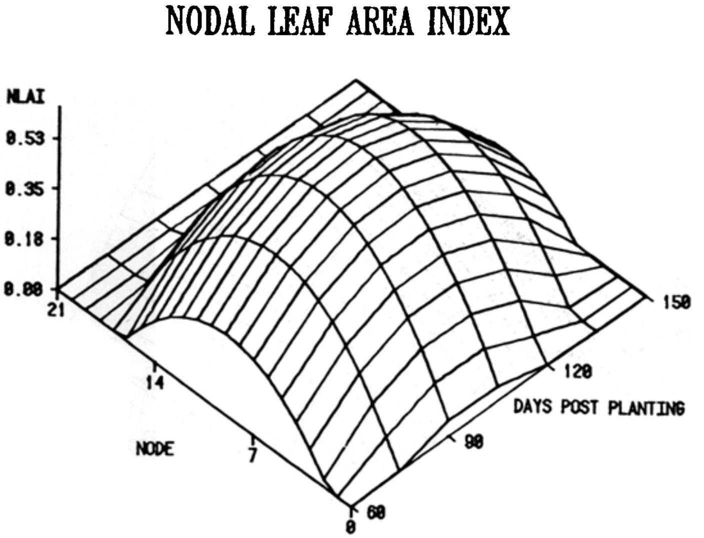


Fig. 7. Leaf area index at each nodal position as affected by time in days after planting for Bragg soybean.

weight, actual leaf areas of the lower nodes were somewhat variable during the growing season due to leaf abscission. Peaks in NLAI were associated with branching. For example, 30 percent of the total plant NLAI was contributed by nodes 4, 8, and 12. A uniform decrease in NLAI occurred above node 12 to the top of the canopy. The maximum NLAI of 0.79 was found at node 7 on 31 August.

Stem Internode Lengths and Weights per Unit Length

The average internode length of stem segments decreased to node 3 then increased to a maximum of 8.4 cm around node 12 late in the season (Fig. 8 and Table 1). The initial decrease may have been related to a brief period of hot, dry weather in early June, prior to the first date of plant sampling. It appears that, once formed, the internode lengths increased rapidly and that little expansion occurred at nodes lower than node 12 after bloom initiation (1 August). Due to the determinate growth characteristic of the Bragg cultivar, all internode expansion ceased by the third week of August. Bernard[1]

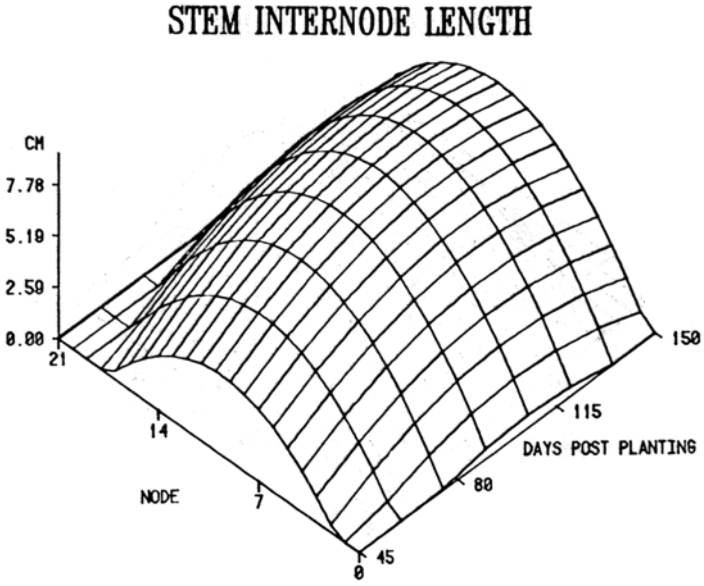


Fig. 8 Length of each mainstem internodal segment (in cm) as affected by nodal position and by time in days after planting for Bragg soybean.

suggested that determinate soybeans abruptly terminate stem growth at the end of flowering whereas semideterminate soybeans terminate after a relatively long-flowering period. He attributed the thick stem tip usually associated with determinate soybeans to the continuation of growth in stem diameter after internode expansion ceased. For the Bragg cultivar our results show that for nodes lower than 12, internodal expansion was terminated at flowering. Expansion of the higher internodes ended by the R4 growth stage. Therefore, even though flowering represented a transition in sink demand from vegetative to reproductive organs, these soybeans grew vegetatively until R4 by initiating and expanding new nodes above node 12.

Stem internode growth was also evaluated by calculating the ratio of internode dry weights to internode length (Fig. 9 and Table 1). After bloom, stem growth continued by increasing the number, the weight, and length of the individual internodes. With the exception of the terminal internode during vegetative growth, the weight to

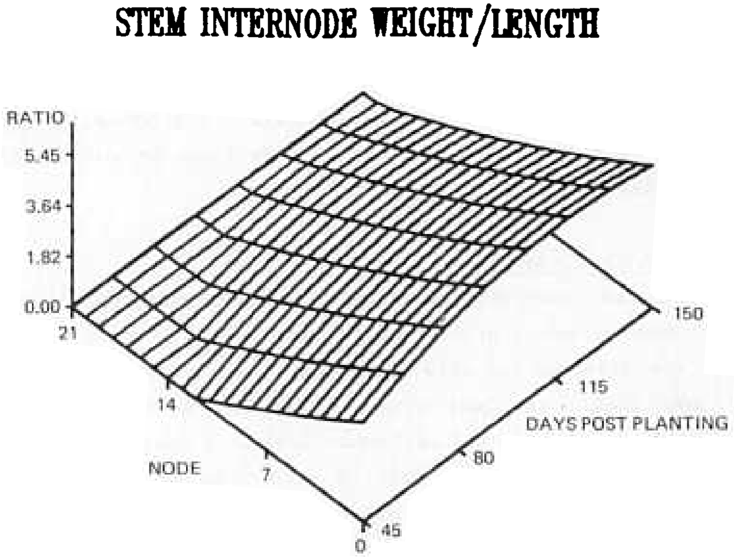

STEM INTERNODE WEIGHT/LENGTH

Fig. 9 Ratio of mainstem internode segment weight to internode segment length (in g/cm) as affected by nodal position and by time in days after planting for Bragg soybean.

TABLE 2

Average values of crop growth rate (CGR), relative growth rate (RGR), net assimilation rate (NAR), leaf area ratio (LAR), specific leaf area (SLA), and leaf weight ratio (LWR) for Bragg soybeans. These values were calculated from whole plant dry weights and leaf areas.

Interval	CGR	RGR	NAR	LAR	SLA	LWR
	$g/m^2/day$	$g/g/day \times 10^2$	$g/m^2/day$	$m^2/g \times 10^4$	$m^2/g \times 10^3$	$g/g \times 10^2$
6 July-19 July	6.70	6.28	-	-	-	53.29
19 July-1 Aug.	14.91	6.21	5.33	120.98	25.95	46.25
1 Aug.-10 Aug.	15.67	3.76	3.71	101.44	26.73	38.19
10 Aug.-21 Aug.	13.79	2.46	2.48	99.88	28.59	34.92
21 Aug.-31 Aug.	16.24	2.25	2.47	91.48	27.39	33.39
31 Aug.-14 Sept.	5.18	0.62	0.77	80.34	26.76	30.08
13 Sept.-27 Sept	7.50	0.81	1.25	65.28	26.56	24.57

length ratio decreased linearly with increase in node number. Linear regression of the ratio vs. node number for the six sampling dates after 21 August (R4 growth stage) had an average intercept, slope, and correlation coefficient of 5.03, -0.274, and 0.993, respectively. The linear decrease in weight per unit length reflects uniform tapering of the stem with height.

Whole-Plant Growth Analyses

Growth was analyzed quantitatively using traditional techniques [16,23]. Average values of crop growth rate (CGR), relative growth rate (RGR), net assimilation rate (NAR), leaf area ratio (LAR), specific leaf area (SLA), and leaf weight ratio (LWR) were calculated from whole plant dry weights and leaf areas between 6 July and 27 September (Table 2). Values of CGR (rate of production of dry weight) were stable from late vegetative to mid-podfill. These data are similar to data of Koller et al.[12] and Scott and Batchelor[18]. The lowest CGR values occurred during early vegetative and late reproductive growth.

Values of RGR, NAR, LAR, and LWR declined with plant age. The relationships between these growth analysis parameters and plant age could be described with either linear or exponential regression models (Table 3). In Bragg soybeans by mid-podfill, a decrease was found in the efficiency of the plant as a producer of new dry weight which appears related to a loss in photosynthetic activity of the leaves.

TABLE 3
Regression parameters of linear and first order decay models of four growth analysis components.

Growth analysis component	Regression model	Regression Parameter intercept	slope	correlation coefficient
RGR	Linear	0.1095	-0.0913	-0.952
	Exponential	0.4747	-0.0354	-0.939
NAR	Linear	9.413	-0.0744	-0.923
	Exponential	35.162	-0.0305	-0.891
LAR	Linear	0.0176	-0.9080	-0.981
	Exponential	0.0229	-0.0100	-0.979
LWR	Linear	0.705	-0.3926	-0.978
	Exponential	0.887	-0.0106	-0.990

The proportion of leaf weight to whole plant dry weight declines uniformly throughout the season as whole plant weight increases. Values of SLA which are measures of the area produced per unit leaf weight unlike the other growth indices, remained relatively constant and averaged 0.017 m^2/g.

Our results can be compared with those obtained by Koller et al.[12] who used growth analysis techniques to quantify the growth of field grown, indeterminate cultivar, Amsoy. They found that CGR rose to a peak and then declined whereas RGR and NAR declined as the season progressed until early August, then rose to a secondary peak in mid-August. They attributed the increases in RGR and CGR during August to the concurrent increase in NAR. A peak was also observed in SLA during early August approximately three weeks before the peaks in RGR, NAR, and CGR. Values of LWR and LAR declined as the season progressed.

Seasonal Dry Weight Sample Variability

The relative sample variability was determined by computing coefficients of variation (CV) for the whole plant and its component parts (Fig. 10). Seasonal values of CV for the whole plant and its components were relatively constant (as borne out by the low R^2 values for CV surface responses, which are discussed below). When dry weights were combined across nodes, values of CV for the stems, petioles, leaves, and pods were 23.4, 38.2, 25.5, and 26.8%, respectively. The sample variability of the petioles was about 50% greater than that of the other plant components. Again, this is in part related to the inclusion with petioles of lateral branches which had their onset at about the time when petiole CV's would otherwise have stabilized. When the dry weights were combined across all plant parts, nodes, and sampling times, the CV of total plant shoot weight was 24.8%.

Seasonal CV values of the combined weight of plant parts by nodes and of components by nodes are presented in Figs. 11a-11e and Table 1. When the plant components at the nodes were growing and developing, the combined plant sample variability was relatively high, and often the CV values were greater than 100%. As the plant components matured values of CV for a given node usually decreased to a relatively constant level except at the lower nodes where increased CV values reflected variability caused by abscission of leaves and true petioles.

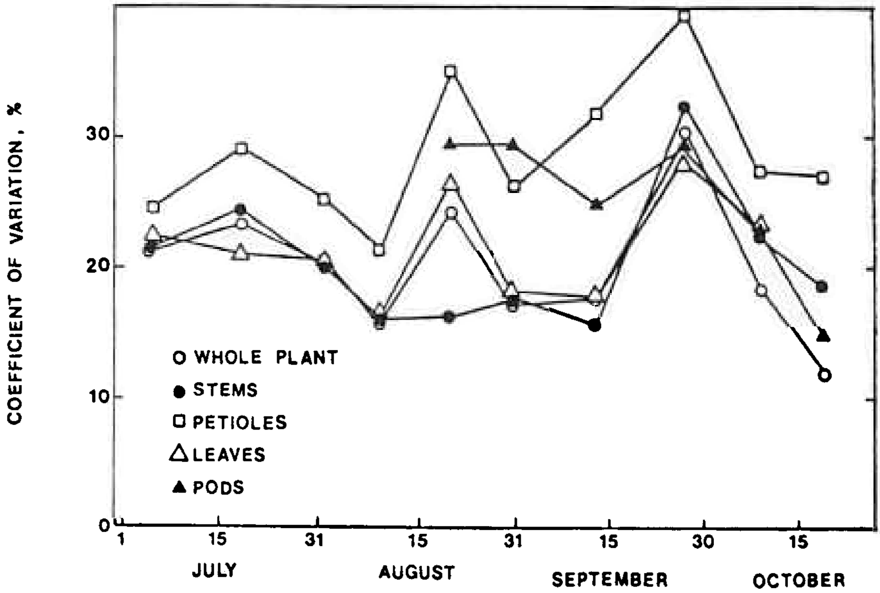


Fig. 10. Seasonal values of the coefficient of variation for the whole plant and for individual component parts of Bragg soybean.

Immature stems, petioles, and leaves had relatively high CV values, and at the end of the growing season as the plant matured the sample, variability of the petioles and leaves increased due to abscission. The CV's of true petioles would be much higher at the end of the season if branches were not included in this growth component. Generally, the sampling variability of the pods was relatively constant and was highest at the lower and upper parts of the canopy and lowest in the middle of the canopy.

CONCLUSIONS

This study has shown that partitioning of assimilates by nodes in Bragg soybeans varies with node position and age. Most first and second order branching occurred between nodes 4 and 8. Vegetative growth of branches and the mainstem continued briefly beyond the onset of reproductive growth. Partition coefficients generally showed that prior to pod initiation partitioning of assimilates favors leaf growth,

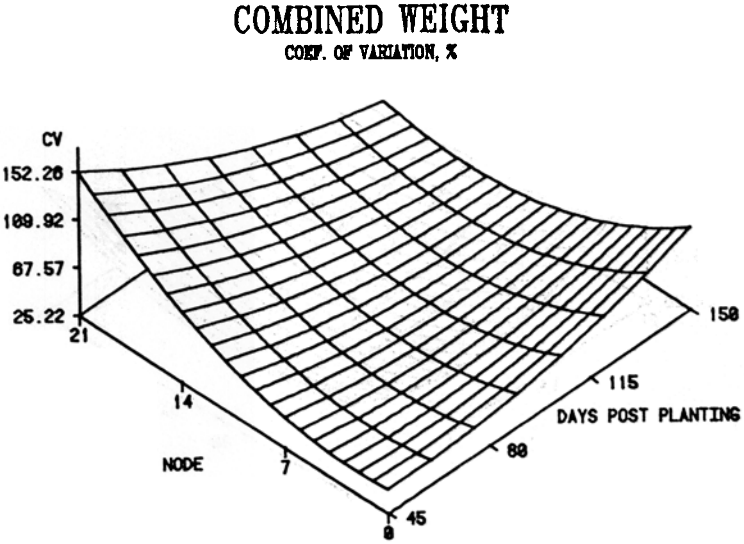


Fig. 11a. Percent coefficient of variation for combined weight of plant parts at each nodal position as affected by time in days after planting for Bragg soybean.

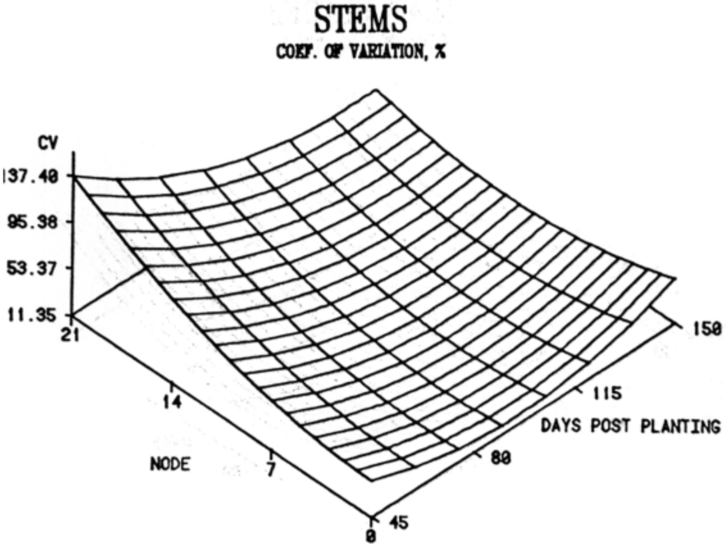


Fig. 11b. Percent coefficient of variation for weight of mainstem internodal segments at each nodal position as affected by time in days after planting for Bragg soybean.

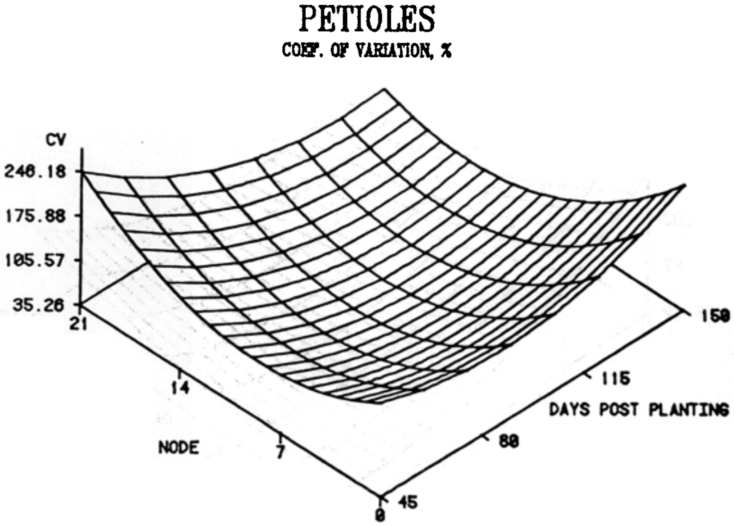


Fig. 11c. Percent coefficient of variation for weight of petioles (+ branches) at each nodal position as affected by time in days after planting for Bragg soybean.

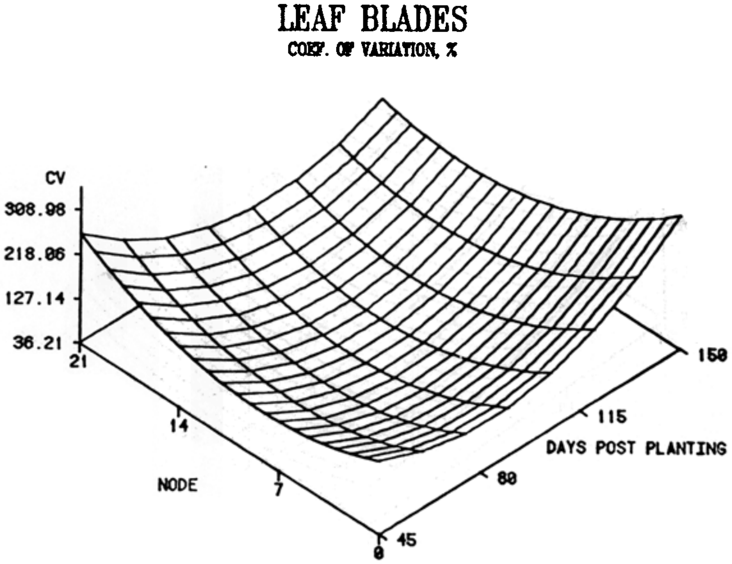
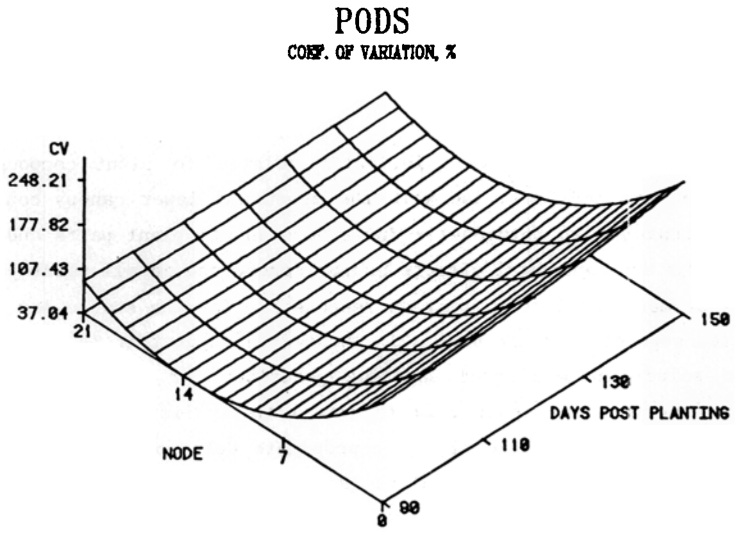


Fig. 11d. Percent coefficient of variation for weight of leaf blades at each nodal position as affected by time in days after planting for Bragg soybean.



PODS

COEF. OF VARIATION, %

Fig. 11e. Percent coefficient of variation for weight of pods at each nodal position as affected by time in days after planting for Bragg soybean.

but following pod initiation increasingly greater proportions of new assimilates are allocated to pod development. Dry weights of leaves and petioles were most variable in the lower-most and upper-most 4 or 5 nodes attesting to the greater responsiveness of these nodal positions to environmental and ontogenetic influences. Stem weights were less variable at a given node than petiole or leaf weights. The fraction of assimilates partitioned to petioles increased (due to branching) until pod initiation, and decreased thereafter due to podfill and cessation of vegetative growth. Pod weights increased uniformly with time at all node positions. Maximum pod weight occurred at the central nodal position. Maximum LAI was associated with branching in midcanopy, whereas there was a uniform decrease in LAI above the zone of branching to the uppermost nodal position.

Internode length of main stems increased rapidly after formation of each node. Expansion of nodes 12 and lower had reached maximum values by bloom initiation. New node development and further node development had ceased by the R4 growth stage (3 weeks after bloom initiation). The main stem tapered uniformly from the lowest node to the uppermost node with a linear decrease in internode weight per unit internode length.

Sample variability was distinctly related to plant component, plant age, and node position with the upper and lower canopy contributing error due to ontogenetic influences in all plant parts and due to negative environmental effects and/or senescence in all plant parts except stems. The latter point is responsible for the stable low CV's for stem segments through node 12. These data suggest it is possible: 1) to select optimum nodal sampling positions for various sampling dates throughout the season, 2) to substantially limit sampling error at a given nodal position by an appropriate delay in sampling after time of node initiation, and 3) to identify the sample variability of specific plant parts at a given nodal position for a single seasonal sampling at maximum vegetative expression (R4) or for combined analysis from multiple sample collection dates.

Generally, during rapid growth the sample variability was high in newly initiated plant components. With the onset of maturity and senescence, processes such as abscission and differential growth rates lead to high sample variability of leaves and petioles with the onset of maturity and senescence. Our data indicate an optimum node can be selected for a given date in order to sample a given plant part with the lowest chance of random variability. Conversely, our data indicate a period of from 2-4 weeks following node initiation (longer with higher node numbers) is required for maturing of a given plant part to minimize sampling error at a given node position when sampling by nodal position.

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