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BRAGG SOYBEANS GROWN ON A SOUTHERN COASTAL PLAIN SOIL II SEASONAL CHANGES IN NODAL K, Ca, AND Mg CONCENTRATIONS

KEY WORDS: Cation exchange, Glycine max, potassium, calcium, magnesium

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ABSTRACT

Determinate soybean (*Glycine max*) has been characterized by very few detailed nutrient partitioning studies. Knowledge of the variation in nutrient concentrations with plant part, nodal position, and plant age is needed for a better understanding of plant function. The information will benefit soybean nutrient modeling and diagnostic interpretation of plant analysis. In this study, 'Bragg' soybean were grown on an Aquic Paleudult soil (Series Goldsboro loamy sand). Plants were sampled at 10 to 14-day intervals beginning 44 days after planting (July 7) until harvest. Maximum observed K concentrations were 5.27, 5.05, 2.88, and 2.99% for stem internodes, petioles (+ branches), leaf blades, and pods, respectively. Maximum observed Ca concentrations were 1.05, 1.98, 2.48, and 1.47% for the same respective plant parts. Maximum observed Mg concentrations were 0.63,

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0.81, 0.65, and 0.58% for the same respective plant parts. Nodal and temporal mean concentrations of K and Ca generally varied considerably due to plant age and nodal position, respectively, in all plant parts. Mean concentrations of Mg were largely unaffected by either plant age or nodal position. Peak concentrations of Ca and Mg are generally associated with upper nodal positions. As new nodes are initiated, the expanding tissue represents an identifiable sink for K. Of importance in plant analysis is the observation that mean concentrations of elements in all four plant parts can vary by two fold or more depending upon plant age and nodal composition of the sample.

INTRODUCTION

Soybean [*Glycine max*. (L.) Merr.] partitions nutrient elements into its component plant parts during growth and development. Detailed effects of plant age and/or morphology on cation concentration for determinate soybean have been reported for field conditions in only a few studies (Ohlrogge, 1960; Leggett and Egli, 1980; Karlen et al., 1982; Henderson and Kamprath, 1970; Sabbe, 1974; and Batchelor et al., 1984). A more detailed understanding of these phenomena in determinate cultivars is needed to guide development of nutrient modeling concepts, to better understand nutrient concentration changes within the plant for diagnostic purposes, and to validate existing concepts related to translocation of mineral nutrients. Although determinate soybean account for a significant part of the U.S. and South American hectarage, most existing nutrient data describe indeterminate cultivars. The authors are unaware of any studies reporting seasonal analyses on a nodal basis for all plant parts.

A study was established on a southeastern U.S. Coastal Plain soil to evaluate the seasonal growth and development by nodes and component parts (Scott et al., 1983), and nutrient relationships of a widely used determinate soybean cultivar grown under field conditions. In this paper, the seasonal changes in K, Ca, and Mg concentrations of various plant parts as influenced by node position are presented. Iron, Zn, Mn, P, and N will be addressed in subsequent papers.

METHODS AND MATERIALS

A detailed description of field layout and operations, experimental design, and plant sampling has been presented by Scott et al.

(1983). Briefly a field study was conducted in 1979 at the Clemson University Research and Education Center near Florence, South Carolina, on a Goldsboro loamy sand (Aquic Paleudult). The experiment site, described by Doty and Parsons (1979) was equipped with a combination drainage-subirrigation system. Soil water status was monitored and regulated with tensiometers.

A determinate soybean cultivar 'Bragg' in maturity group VII was grown. Fertilization was according to South Carolina soil test recommendations, and weed and insect control were achieved with appropriate chemical applications and timely cultivation. Soybeans were conventionally planted to a stand of 220,000 plants/ha on May 23 in rows 1 m wide and 75 m long within the 1-ha field. The experimental design was a nested factorial with four sampling locations and four subsamples at each location. Plants in a 0.30 m^2 area were counted and severed at the soil surface from 7 July to 17 October at 10- to 14-day intervals. Four representative plants were chosen, brought to the laboratory, and separated by nodes into component parts of stems (main stems only), leaves (leaf blades only), petioles (including branch stems at that node), and pods. This sectioning scheme was employed to accommodate conceptual requirements of nodally segmented mineral nutrient uptake models developed by Scott and Brewer (1980, 1982) and Sallam et al. (1985). Nodes were numbered and growth stages identified using the conventions of Fehr et al. (1971). Each numberèd internodal main stem segment was made up of the identified node ($node_n$) and internodal tissue between it and the next lowest numbered node ($Node_{n-1}$). Plant height and weight of dropped leaves and true petioles were determined throughout the season. The partitioned dry matter components were oven dried at 60 C, ground, and digested with a 1:1 nitric:perchloric acid mix. The K concentration was determined by flame emission spectrophotometry. Concentrations of Ca and Mg were determined by atomic absorption spectrophotometry. A solution of 1% La was added to prevent anion interferences in Ca analysis.

An analysis of variance was performed on the data considering sample locations in the field, subsamples, 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. Statistical evaluation was not possible in some cases because sample size required extensive pooling of samples for nutrient analysis. For development of statistical response surfaces, dependent variables were regressed over time and nodal position.

RESULTS AND DISCUSSION

Stem Internodes

Maximum observed concentrations of K, Ca, and Mg in internodes were 5.27%, 1.05%, and 0.63%, respectively. These occurred at nodes 15, 7, and 7, respectively, on 70, 44, and 44 days after planting, respectively. Mean internode concentration of K (Fig. 1) generally declined through the season until reaching a plateau concentration of about 0.9% during the last four sampling dates. Mean internode K concentrations in all but the last internodal segment averaged 1.0 to 1.7% and were generally slightly higher in the upper third of the canopy (Fig. 2). Peak K concentrations were associated with juvenile tissue, occurring at internodes near the top of the canopy on any given observation date. Similarly, dates of peak K concentration at a given internode became progressively later with higher internodal positions. These data suggest that as new nodes are initiated, the expanding tissue represents a sink for K. As ontogeny progresses this sink moves to higher nodal positions and the concentration of K required to sustain growth in areas of tissue expansion increases in proximity to the nodal position of greatest sink strength. The statistical response surface of K (Fig. 3) shows a gradual shift of high concentrations from low nodal positions to upper nodal position as the season progresses.

Previous data from this experiment (Scott, et al., 1983) showed that 8 or 9 nodes remained to be developed on the main stem at the onset of flowering (R1). There is, therefore, considerable sink strength in the upper canopy late in the season as substantial vegetative growth progresses along with pod development in the Bragg cultivar.

Table 1 contains the polynomial relationships needed to calculate nutrient statistical response surfaces. Appendix Table A. contains the polynomial relationships for growth components. In the original presentation of Table A (Scott et al., 1983), non-significant parame-

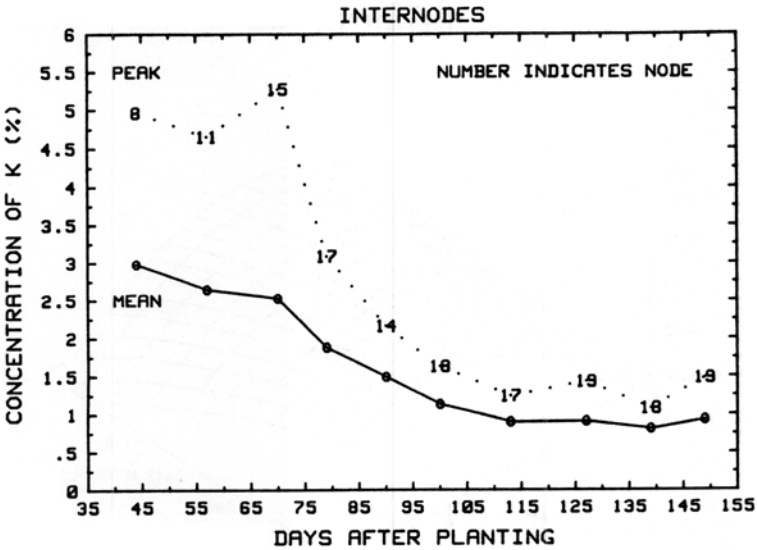

FIG. 1. Internode K% vs Time. Numbers are Node of Peak K%

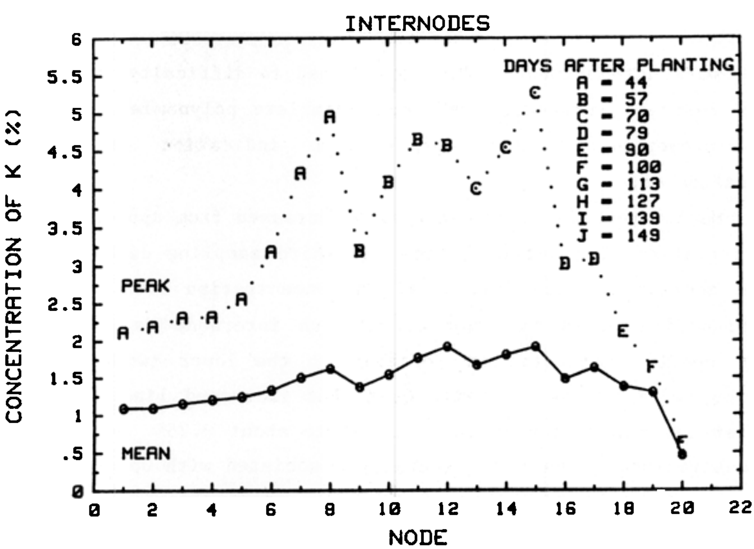

FIG. 2. Internode K% vs Node. Letters are Date of Peak K%

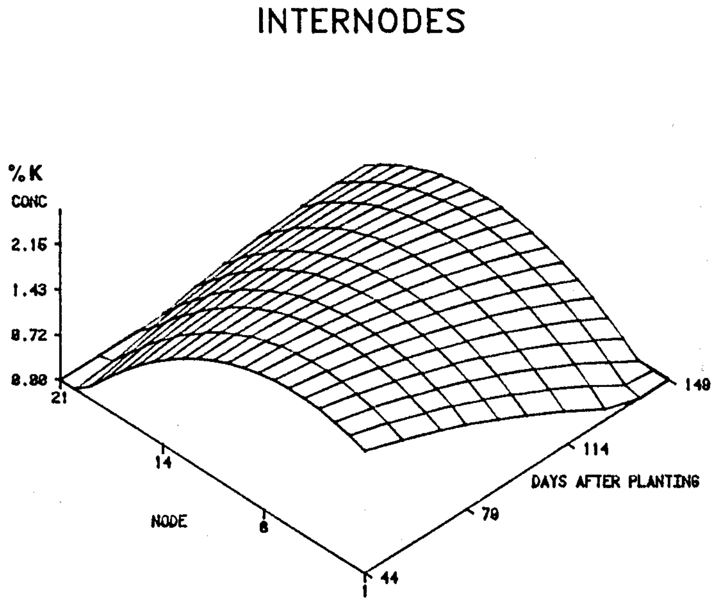

FIG. 3. Internode K% Statistical Response Surface for Node and Time.

ters were not included. This could lead to difficulty in reproducing some response surfaces, therefore, complete polynomial relationships are presented in this paper with indication of statistical significance.

Mean internode Ca concentration decreased from approximately 1.0% to a plateau of about 0.4% from the third sampling date on (Fig. 4). This decline in mean internodal Ca concentration over time was less pronounced than in the case of K. Mean internode Ca concentrations were nearly unaffected by position in the lower two-thirds of the canopy, with values of about 0.4%, but increased linearly with node number beginning at node 14 (Fig. 5) to about 0.75%. As with K, peak concentrations of Ca were generally associated with upper nodal positions. The statistical response surface of Ca (Fig. 6) is similar to that of K but with higher relative concentrations in the upper nodal positions at late sampling dates.

TABLE 1

Mathematical and Statistical Description of Response Surface Relationships for the Named Parameters using the Equation Form $Y = a + b(node) + c(node)^2 + d(date) + e(date)^2 + f(node)(date)$. Factors Not Significant at the 0.1 Level of Probability are Indicated as "NS" under the Table Entry.

Parameter	Coefficients a	b	c	d	e	f	Combined R^2
Stem internode K	2.360	0.054 NS	−0.011	−0.009 NS	−0.00008 NS	0.0015	0.33
Stem internode Ca	0.633	−0.026	−0.001	0.0006 NS	−0.00003	0.0005	0.28
Stem internode Mg	0.163	0.014	−0.002	0.002 NS	−0.00003	0.0003	0.42
Petiole (+ branches) K	1.058 NS	0.156	−0.019	0.043	−0.0004	0.002	0.51
Petiole (+ branches) Ca	0.087 NS	0.042	−0.005	0.008 NS	−0.00006	0.0008 NS	0.41
Petiole (+ branches) Mg	2.212	−0.096	−0.0008 NS	−0.026	0.00008 NS	0.001	0.10
Leaf blade K	−0.361 NS	0.102	−0.011	0.047	0.0003	0.0007	0.48
Leaf blade Ca	−0.040 NS	0.086	−0.007	0.011	−0.00005	0.0006	0.45
Leaf blade Mg	−0.135 NS	0.032	−0.003	0.010	−0.00006	0.0002	0.52
Pod K	1.590 NS	0.186	−0.015	0.004 NS	−0.00007 NS	0.001	0.51
Pod Ca	3.524	0.052	−0.004	−0.041	0.0001	0.0002 NS	0.56
Pod Mg	0.635 NS	0.040	−0.003	−0.003 NS	−0.000002 NS	0.0002	0.49

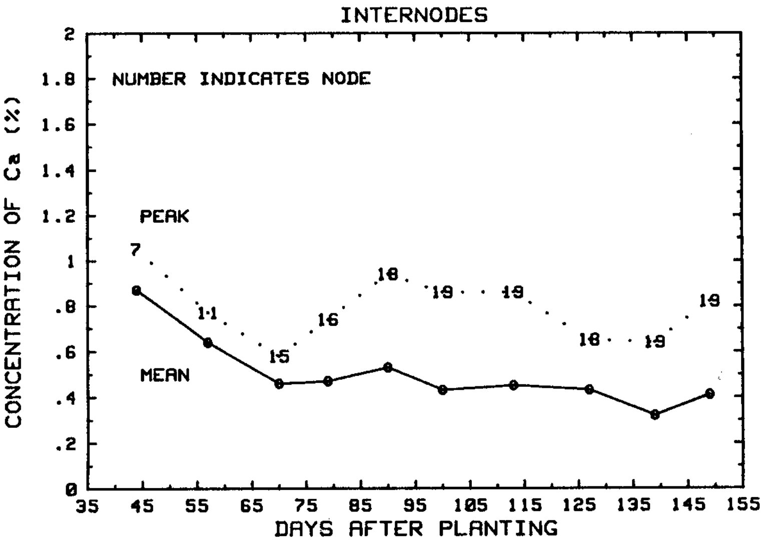

FIG. 4. Internode Ca% vs Time. Numbers are Node of Peak Ca%.

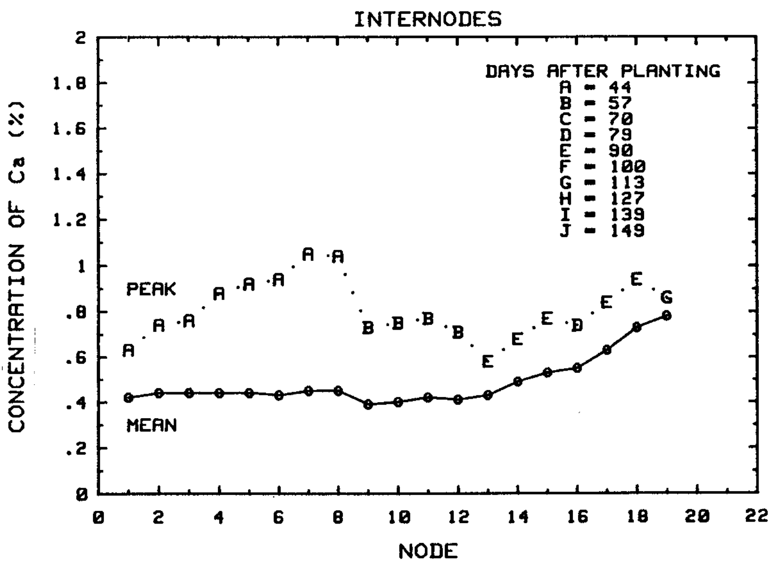

FIG. 5. Internode Ca% vs Node. Letters are Date of Peak Ca%.

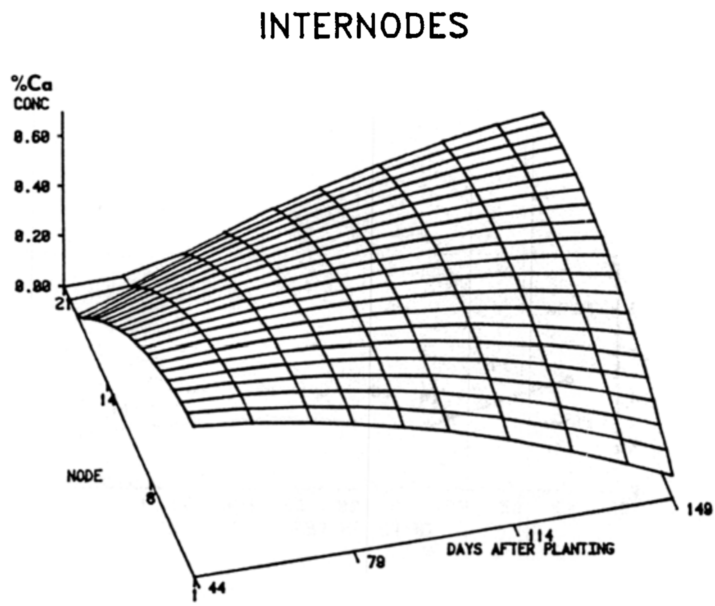

FIG. 6 Internode Ca% Statistical Response Surface for Node and Time.

Mean internode Mg concentration (Fig. 7) decreased early in the season to a plateau of about 0.3%. Increases in mean internode Mg concentrations were nearly linear with nodal position from a low of 0.16% at node 1 to a high of 0.39% at node 19 (Fig. 8). Peak concentrations were again generally associated with upper nodal positions. Differences observed between peak and mean Mg concentrations over time (Fig. 7) remain nearly constant at approximately 0.2 percentage points. Difference between peak and mean Mg concentration was greatest in mid-canopy (Fig. 8). The statisitcal response surface of Mg (Fig. 9) is more similar to that of K than that of Ca.

Least significant differences and coefficients of variation for mean concentrations are presented for nodal sources of variance (LSD_n and CV_n, respectively) and temporal sources of variance (LSD_t and CV_t, respectively) for K, Ca, and Mg in Tables 2 and 3. Incomplete data result from the need in some instances to pool tissue samples from more than one replication for elemental analysis.

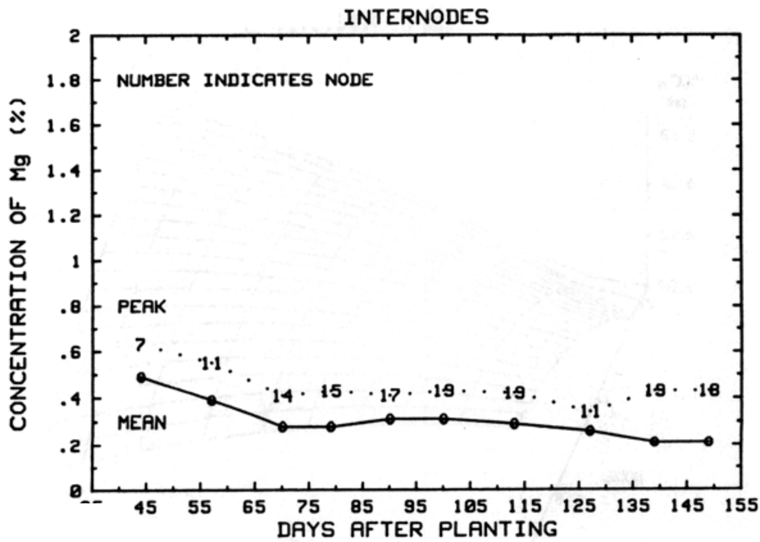

FIG. . Internode Mg% vs Time. Numbers are Node of Peak Mg%

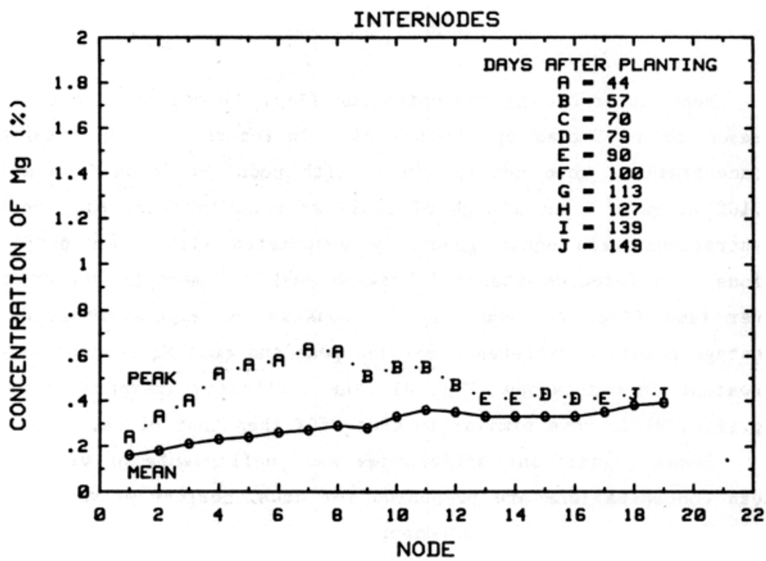

FIG. 8. Internode Mg% vs Node. Letters are Date of Peak Mg%.

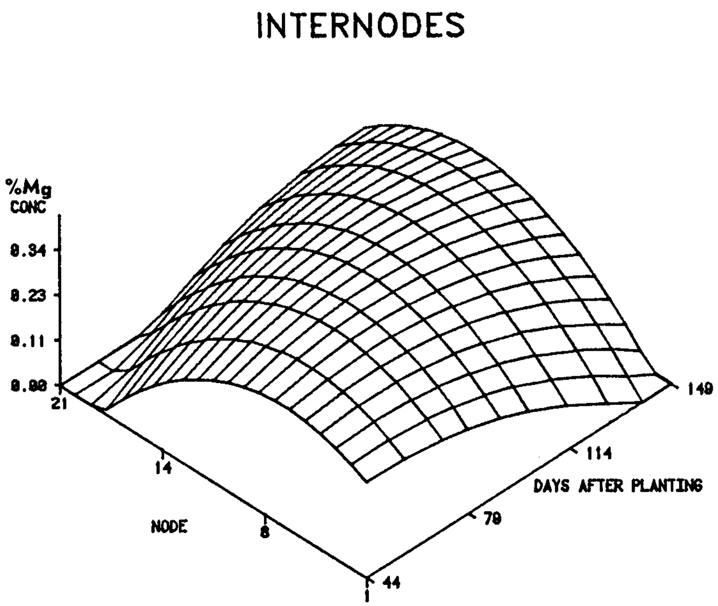

FIG. 9. Internode Mg% Statistical Response Surface for Node and Time.

TABLE 2
Nodal concentration variance of stem internodes

Days after planting	K		Ca		Mg	
	LSD_n	CV_n	LSD_n	CV_n	LSD_n	CV_n
44	0.092	4.39	0.022	3.65	0.015	4.50
57	0.138	7.45	0.029	6.25	0.022	7.92
70	0.175	9.91	0.021	6.32	0.018	9.16
79	0.175	12.94	0.028	8.62	0.018	9.27
90	0.141	13.13	0.030	8.09	0.021	9.53
100	0.089	11.62	0.019	6.74	0.016	7.93

TABLE 3
Temporal concentration variance of stem internodes

Node	K		Ca		Mg	
	LSD_t	CV_t	LSD_t	CV_t	LSD_t	CV_t
1	0.126	16.50	0.022	7.31	0.011	9.70
2	0.099	13.05	0.019	6.19	0.010	7.97
3	0.095	11.81	0.015	4.93	0.013	8.73
4	0.121	14.33	0.021	6.84	0.015	9.05
5	0.120	13.86	0.022	7.07	0.015	8.71
6	0.132	14.09	0.024	7.81	0.018	10.11
7	0.116	11.04	0.023	7.45	0.019	9.87
8	0.122	10.69	0.023	7.38	0.020	10.17
9	0.139	14.75	0.020	7.50	0.020	10.47
10	0.152	14.39	0.016	5.92	0.015	6.58
11	0.196	15.73	0.014	4.82	0.019	7.69
12	0.171	12.71	0.023	7.73	0.022	8.86
13	0.202	17.62	0.025	8.23	0.195	8.47
14	0.193	15.03	0.025	7.30	0.021	8.89
15	0.117	8.47	0.029	7.66	0.015	6.56
16	0.166	15.06	0.035	8.73	0.018	7.46
17	0.126	10.99	0.025	5.65	0.014	5.55

Petioles (+ Branches)

Maximum observed concentrations of K, Ca, and Mg in petioles (+ branches) were 5.05%, 1.98% and 0.81%, respectively. These occurred at nodes 15, 18, and 17, on days 70, 149, and 149 after planting, respectively. Mean nodal K concentrations declined almost linearly with time in the petiole (+ branches) plant fraction (Fig. 10). Peak K concentrations were generally about 0.5 percentage points above mean concentrations. Peak K concentrations moved toward the upper canopy on the first three observation dates but from the fourth observation on, peak K concentration remained associated with nodes five and six. This date (79 days after planting) approximately coincided with the onset of lateral branching. It is likely that peak concentrations of the fifth and sixth nodes were elevated by the inclusion of secondary branch tissue and petioles that resided physically higher in the canopy but which were morphologically associated with these nodes in this particular scheme of partitioning.

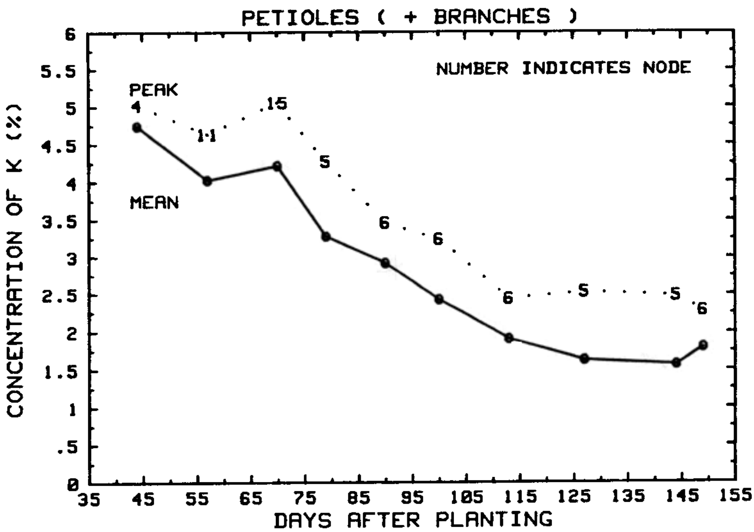

FIG. 10. Petiole K% vs Time. Numbers are Node of Peak K%.

Mean nodal petiole K concentrations increased with node number (Fig. 11) up to the fifth node but then decreased linearly with increasing node number. Peak K concentrations were consistently about 2 percentage points above mean concentrations, and peak concentrations of the higher nodes are generally associated with progressively later observations dates. The statistical response surface of K (Fig. 12) generally peaked at mid-season in mid-canopy.

Mean nodal petiole Ca concentrations were nearly constant over the season at about 1% (Fig. 13). Peak nodal petiole Ca concentrations were about 0.5 percentage points higher than the mean in the early season. These increased to about three times the mean by the last observation and were generally associated with upper canopy positions as the season progressed. Mean nodal petiole Ca concentrations and peak nodal Ca concentrations (Fig. 14) increased with node number. Means increased nearly linearly, whereas peak values were high early and late in the season. The statistical response surface of Ca in

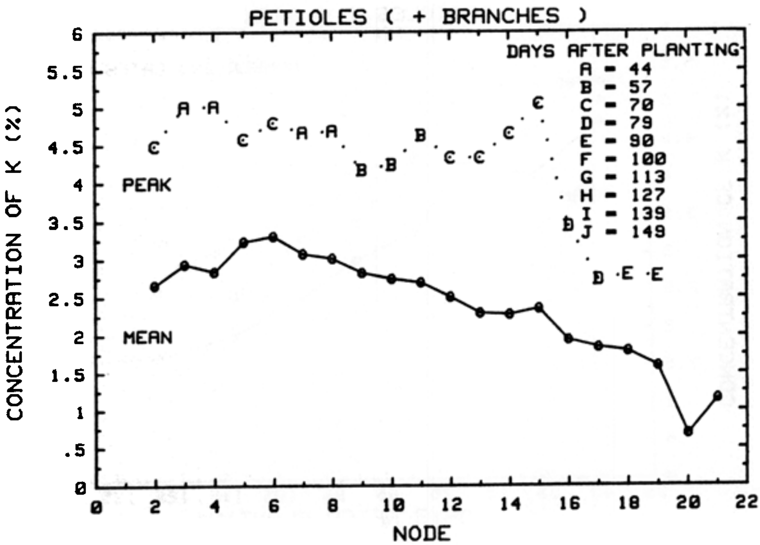

FIG. 11. Petiole K% vs Node. Letters are Date of Peak K%.

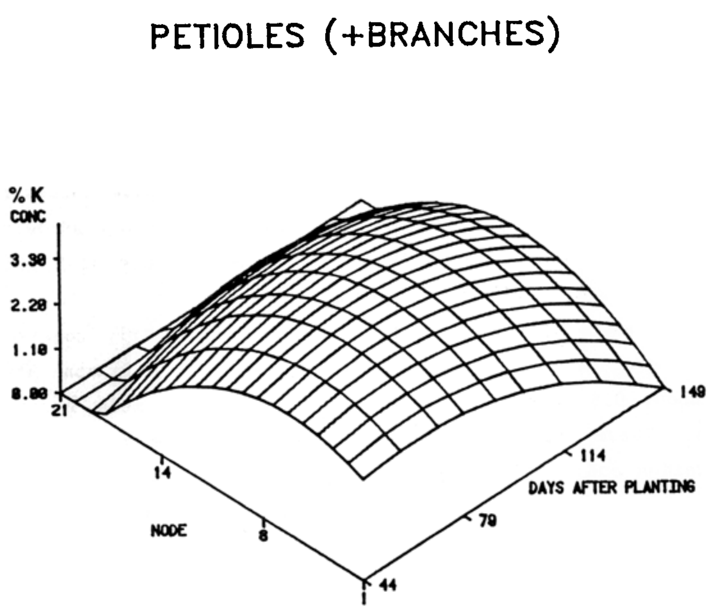

FIG. 12. Petiole K% Statistical Response Surface for Node and Time

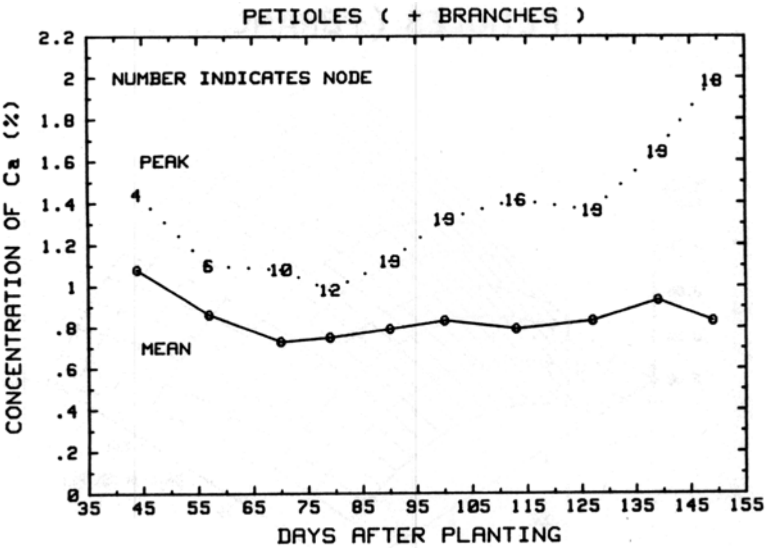

FIG. 13. Petiole Ca% vs Time. Numbers are Node of Peak Ca%.

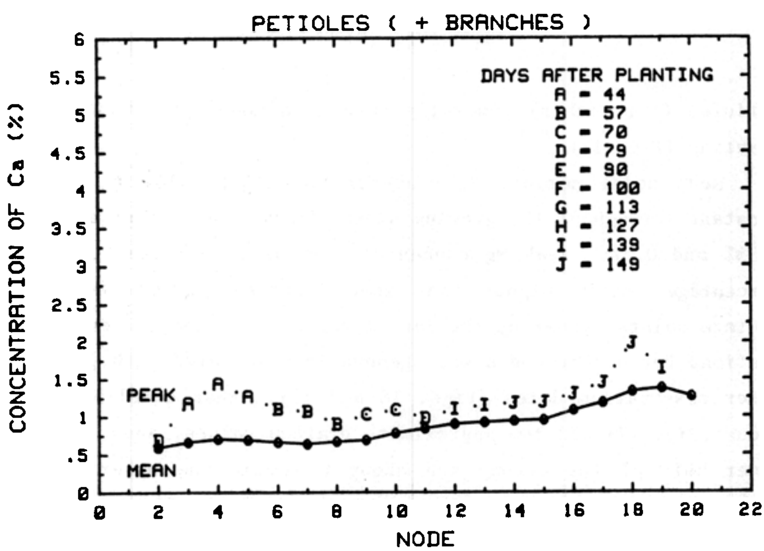

FIG. 14. Petiole Ca% vs Node. Letters are Date of Peak Ca%.

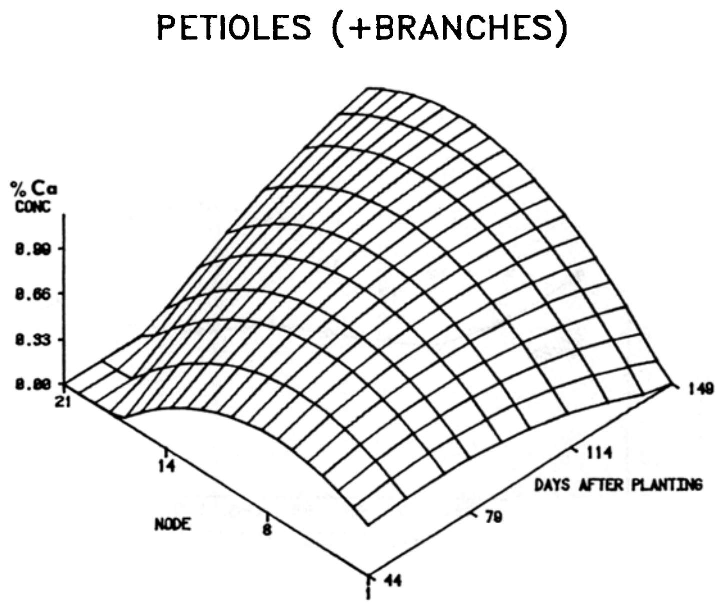

FIG 15. Petiole Ca% Statistical Response Surface for Node and Time

petioles (+ branches) generally rose with node number and days after planting (Fig. 15).

Mean nodal petiole Mg concentrations (Fig. 16) remained nearly constant throughout the growing season between values of approximately 0.35% and 0.5%. Peak Mg concentrations were consistently about 0.15 percentage points higher than means, increasing to about 0.3 percentage points higher on the last three observations. Peak Mg concentrations for higher nodes were generally associated with progressively later observation dates (Figs. 16 and 17). Mean nodal Mg concentrations (Fig. 17) had two approximate plateau values, about 0.35% in the lower half of the canopy and about 0.50% in the upper half of the canopy. Similarly, as with K, this positional effect on Mg concentrations may be due to the combining of upper canopy tissue from second order branches beginning around the sixth to eighth node.

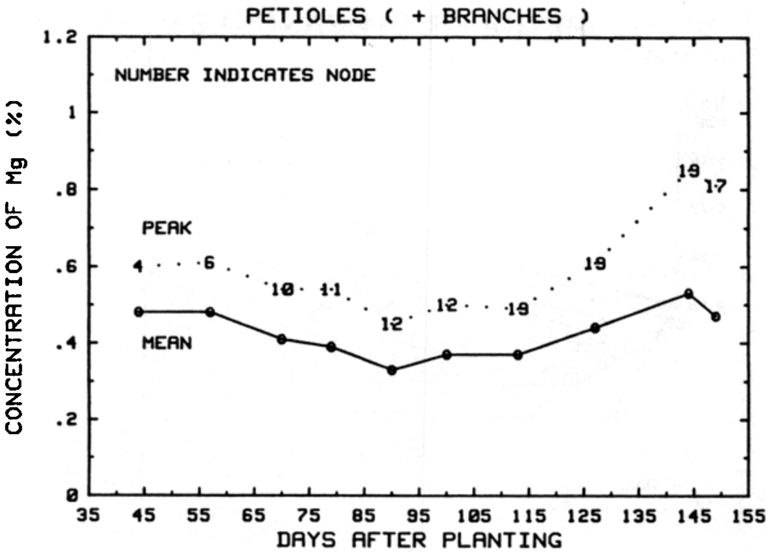

FIG. 16. Petiole Mg% vs Time. Numbers are Node of Peak Mg%.

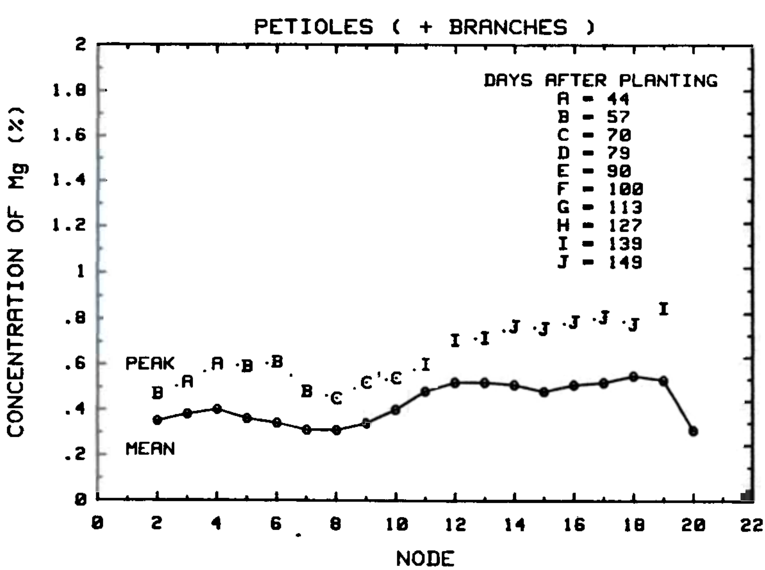

FIG. 17. Petiole Mg% vs Node. Letters are Date of Peak Mg%.

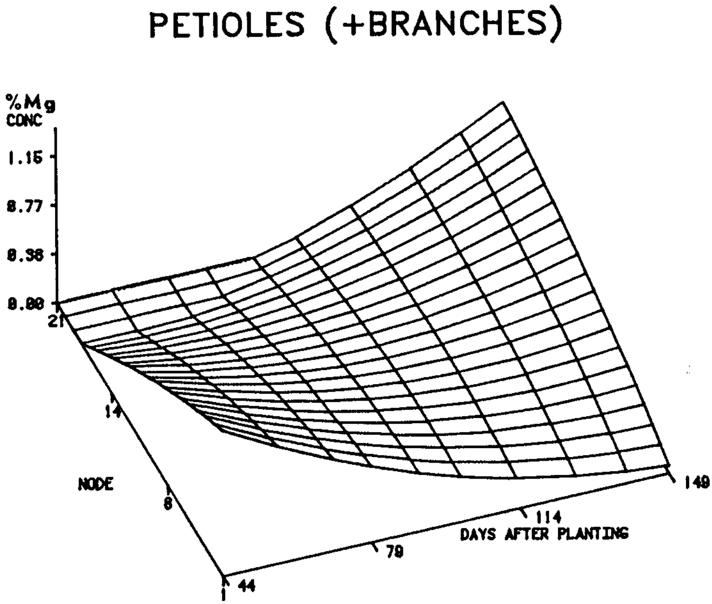

FIG. 18. Petiole Mg% Statistical Response Surface for Node and Time.

Peak Mg concentrations were generally around 0.2 percentage points higher than means across nodal positions. The statistical response surface (Fig. 18) of Mg for petioles (+ branches) is generally saddle-shaped with early peaks low in the canopy and late peaks high in the canopy.

Least significant differences and coefficients of variation for mean concentrations are presented for nodal sources of variance (LSD_n and CV_n, respectively) and temporal sources of variance (LSD_t and CV_t, respectively) for K, Ca, and Mg in Tables 4 and 5.

Leaf Blades

Maximum observed concentrations of K, Ca, and Mg in leaf blades were 2.88%, 2.48%, and 0.65%, respectively. These occurred at nodes 6 and 18 on days 100 and 139 for K and Ca, respectively. The maximum observed concentration of Mg occurred twice, at nodes 4 and 14, on 44

TABLE 4
Nodal concentration variance of petioles (+ branches)

Days after planting	K		Ca		Mg	
	LSD_n	CV_n	LSD_n	CV_n	LSD_n	CV_n
44	-	-	-	-	-	-
57	0.218	7.71	0.069	11.49	0.085	25.64
70	0.269	8.65	0.052	9.93	0.026	9.00
79	0.284	12.08	0.067	11.95	0.038	13.01
90	0.233	11.24	0.058	10.31	0.037	15.87

TABLE 5
Temporal concentration variance of petioles (+ branches)

Node	K		Ca		Mg	
	LSD_t	CV_t	LSD_t	CV_t	LSD_t	CV_t
		-	-	-	-	-
	0.117	5.96	0.013	3.04	0.010	3.93
	0.142	6.84	0.045	9.39	0.028	10.21
	0.108	5.30	0.027	5.52	0.019	6.76
5	0.154	6.56	0.066	13.37	0.021	8.19
6	0.203	8.83	0.029	6.34	0.084	35.24
7	0.210	9.78	0.039	8.57	0.021	9.25
8	0.232	10.91	0.047	10.46	0.029	13.52
9	0.210	10.59	0.063	13.03	0.034	14.35
10	0.198	10.24	0.041	7.52	0.025	8.91
11	0.197	10.38	0.026	4.47	0.024	7.03
12	0.235	12.96	0.038	5.98	0.028	7.82
13	0.189	11.64	0.034	5.17	0.024	6.46
14	0.164	10.14	0.036	5.40	0.023	6.39
15	0.175	10.52	0.024	3.50	0.017	4.80
16	0.116	8.21	0.029	3.74	0.010	2.62
17	0.061	4.62	0.025	2.72	0.010	2.38

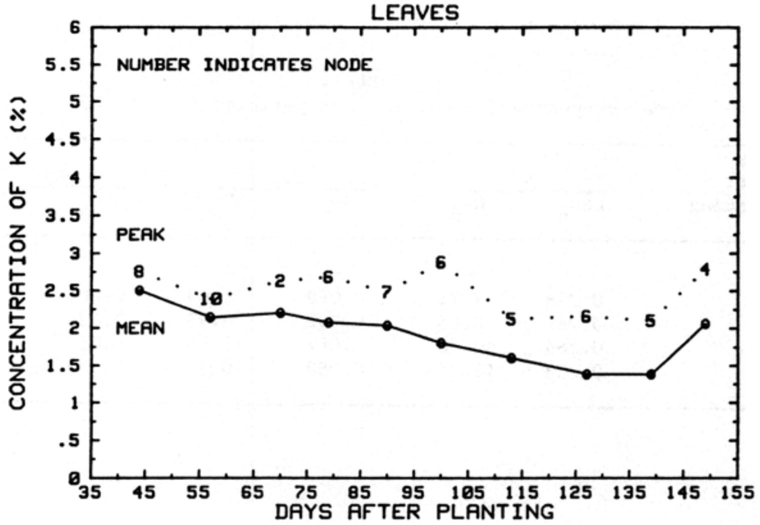

FIG. 19. Leaf K% vs Time. Numbers are Node of Peak K%

and 149 days after planting, respectively. Mean nodal K concentration in leaf blades (Fig. 19) decreased linearly approximately 1 percentage point during the season except for the last observation date when it rose nearly 0.75 percentage point. Peak K concentrations were approximately 0.5 percentage point above mean K concentrations throughout the season, and generally occurred on any given date in the lower one-third of the canopy. This may be partially due to inclusion of all tissue associated with branches at a given node. This would result in inclusion of juvenile tissue from physically higher in the canopy which would elevate the apparent concentrations at lower nodes. Seasonal mean K concentration in leaf blades (Fig. 20) showed a slight decline as node number increased. Peak concentrations were consistently approximately 0.5 percentage point above means, were associated with progressively later dates, and were found at higher nodes. Peak concentrations at highest nodes occurred at mid-season. The statistical response surface (Fig. 21) for leaf blade K generally peaks about mid-season and mid-canopy.

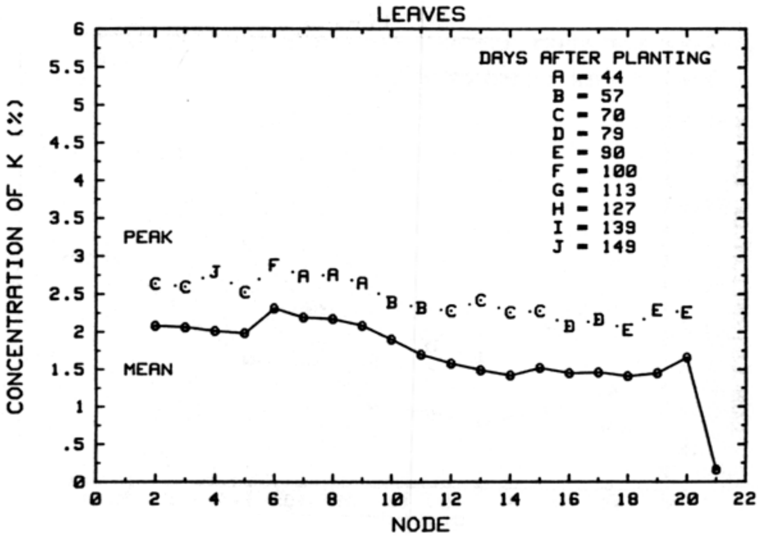

FIG. 20. Leaf K% vs Node. Letters are Date of Peak K%

LEAF BLADES

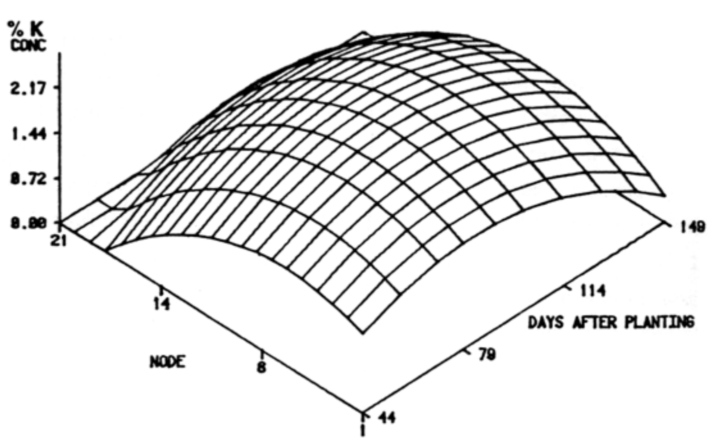

FIG. 21 Leaf Blade K% Statistical Response Surface for Node and Time

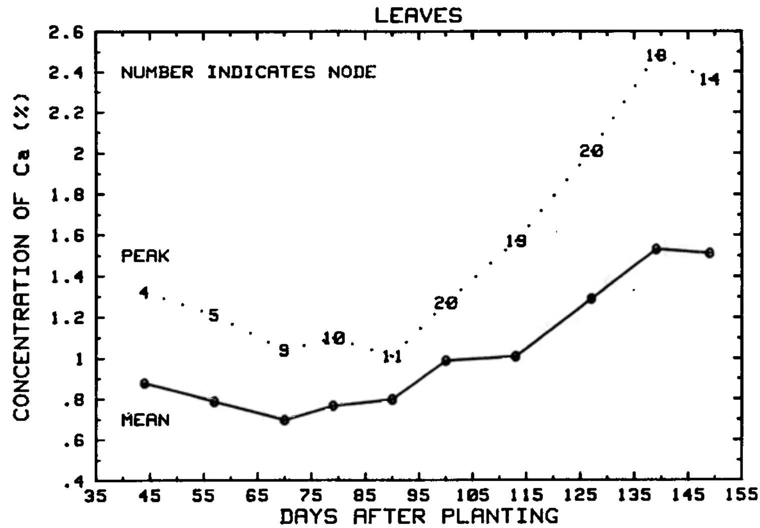

FIG. 22. Leaf Ca% vs Time. Numbers are Node of Peak Ca%.

Mean nodal Ca concentration in leaf blades (Fig. 22) was about 0.8% until between 90 and 100 days after planting. At this time it began to increase linearly to nearly twice that concentration. Peak Ca leaf blade concentrations followed a similar pattern but were generally elevated about 0.4 percentage point above the means. Peak concentrations were generally associated with progressively higher nodes until the last two observations when the peak values came from near mid-canopy. Mean nodal Ca concentrations of leaf blades (Fig. 23) were about 0.8% through the ninth node then rose linearly to the top of the canopy. Peak concentrations at individual nodes rose sporadically from the bottom to the top of the canopy and occurred almost entirely on the last three observation dates. These peak concentrations were generally about 0.4 to 0.6 percentage points higher than the means. The statistical response surface (Fig. 24) for leaf blade Ca was nearly planar and rises with node number and date.

Mean nodal Mg concentrations in leaf blades whether averaged over nodes (Fig. 25) or over time (Fig. 26) were essentially constant at about 0.4%. Peak concentrations (Fig. 25) were generally associated

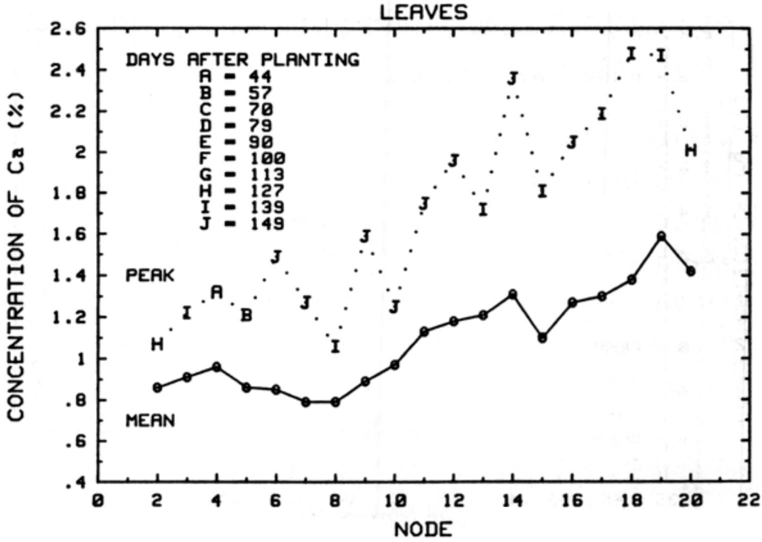

FIG. 23 Leaf Ca% vs Node. Letters are Date of Peak Ca%

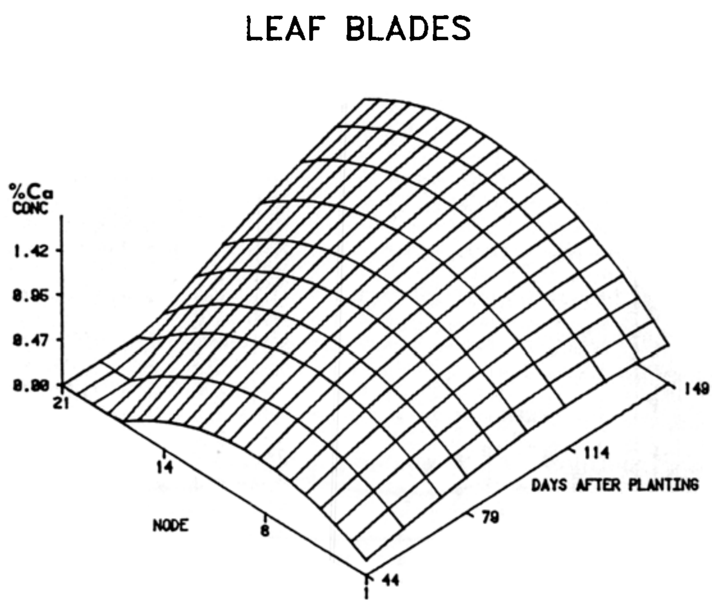

FIG. 24. Leaf Blade Ca% Statistical Response Surface for Node and Time

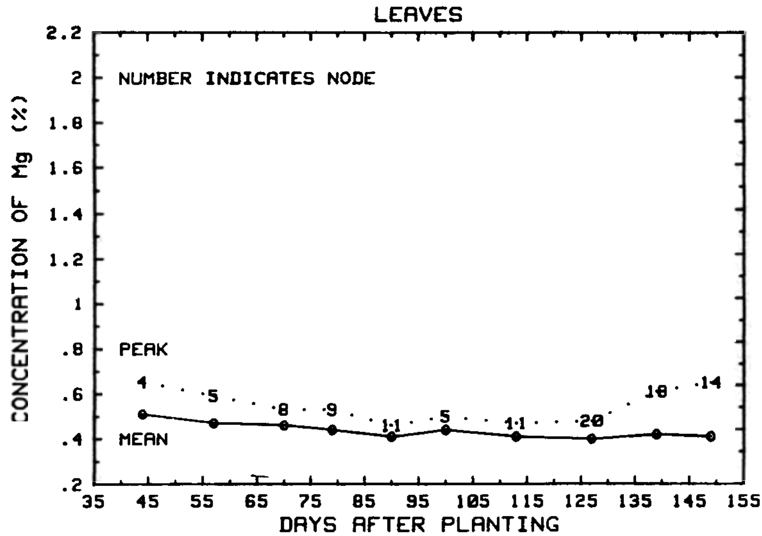

FIG. 25. Leaf Mg% vs Time. Numbers are Node of Peak Mg%.

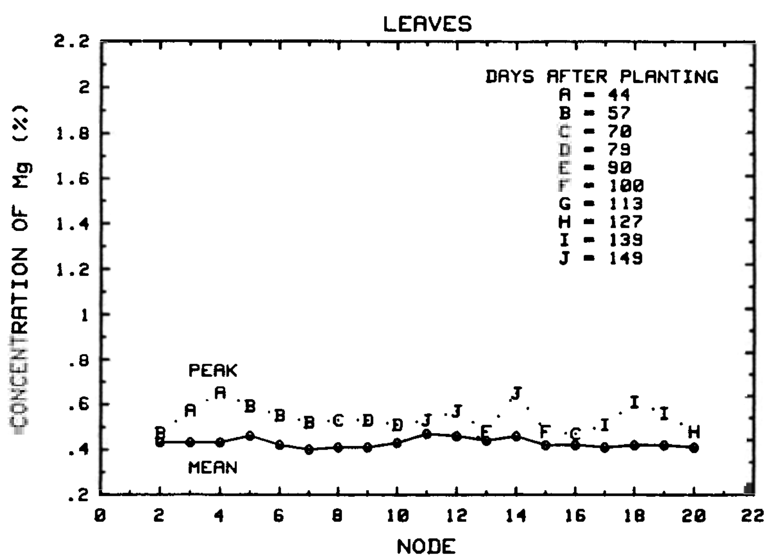

FIG. 26. Leaf Mg% vs Node. Letters are Date of Peak Mg%.

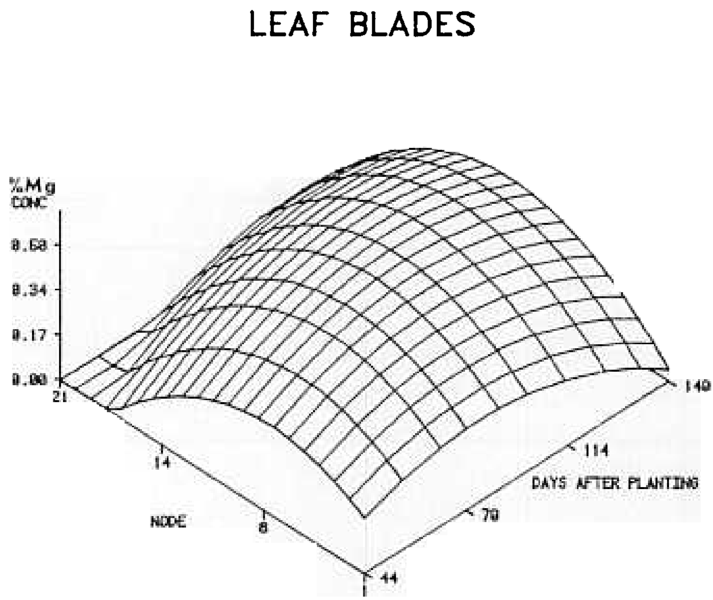

FIG. 27. Leaf Blade Mg% Statistical Response Surface for Node and Time

with progressively higher nodal positions and with later dates (Fig. 26). The statistical response surface (Fig. 27) for leaf blade Mg is highest in the upper half of the canopy and is generally slightly higher late in the season.

Least significant differences and coefficients of variation for mean concentrations are presented for nodal sources of variance (LSD_n and CV_n, respectively) and for temporal sources of variance (LSD_t and CV_t, respectively) for K, Ca, and Mg in Tables 6 and 7.

Pods

Maximum observed concentrations of K, Ca, and Mg were 2.99%, 1.47%, and 0.58%, respectively. These occurred at nodes 6 and 17 on days 100 and 90 after planting for K and Ca, respectively. The Mg peak occurred twice at nodes 9 and 3 on days 90 and 100 after planting, respectively.

TABLE 6
Nodal concentration variance of leaf blades

Days after planting	K		Ca		Mg	
	LSD_n	CV_n	LSD_n	CV_n	LSD_n	CV_n
44	0.174	5.82	0.055	8.81	0.024	6.62
57	0.096	6.35	0.060	10.76	0.023	6.89
70	0.152	9.62	0.071	13.71	0.051	15.18
79	0.157	10.58	0.076	14.09	0.025	7.99
90	0.171	11.73	0.076	13.32	0.023	7.65
100	-	-	0.011	1.63	0.012	3.93

TABLE 7
Temporal concentration variance of leaf blades

Node	K		Ca		Mg	
	LSD_t	CV_t	LSD_t	CV_t	LSD_t	CV_t
1	-	-	-	-	-	-
2	0.059	2.41	0.011	1.69	0.005	1.46
3	0.079	5.36	0.017	2.60	0.016	5.27
4	0.149	10.54	0.062	8.93	0.024	7.77
5	0.146	10.39	0.057	9.15	0.025	7.53
6	0.117	7.14	0.053	8.81	0.022	7.18
7	0.098	6.47	0.057	10.38	0.024	8.59
8	0.144	9.36	0.069	12.52	0.023	8.14
9	0.088	6.05	0.090	14.30	0.019	6.57
10	0.106	7.86	0.060	8.77	0.019	6.16
11	0.109	9.09	0.037	4.68	0.058	17.77
12	0.103	9.29	0.040	4.84	0.015	4.73
13	0.075	7.13	0.038	4.48	0.017	5.47
14	0.118	11.54	0.032	3.37	0.013	4.06
15	0.083	7.61	0.025	3.22	0.011	3.71
16	0.089	8.65	0.012	1.26	0.006	1.87
17	0.105	9.83	0.017	1.83	0.007	2.35
18	0.010	0.99	0.052	5.14	0.017	5.78

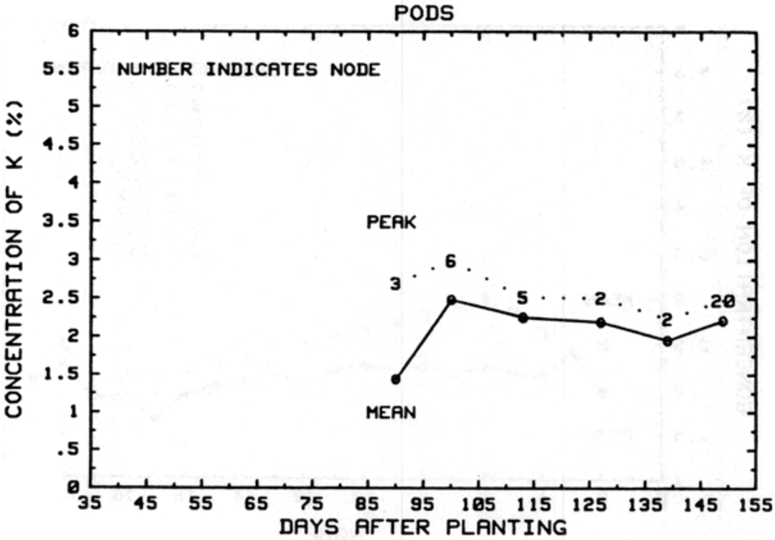

FIG. 28 Pod K% vs Time. Numbers are Node of Peak K%

Mean nodal K concentration in pods (Fig. 28) increased shortly after pod initiation but declined slightly from 100 days after planting to harvest. Except for the first observation, peak concentrations were generally less than 0.5 percentage point higher than nodally averaged means. The seasonal average K concentrations in pods was nearly constant at approximately 2.0% at all nodal positions (Fig. 29). Peak K concentrations at essentially all nodes occurred 100 days after planting during early stages of pod formation. Time averaged peak K concentration in pods generally was approximately 0.5 percentage point higher than means. The statistical response surface (Fig. 30) for pod K peaks at central nodal positions and is relatively unaffected by date.

Mean nodal Ca concentration of pods (Fig. 31) dropped linearly to one-third its original concentration between day 90 and 139. Peak concentrations were generally about 0.1 percentage point above mean concentrations and were most frequently from upper nodal positions.

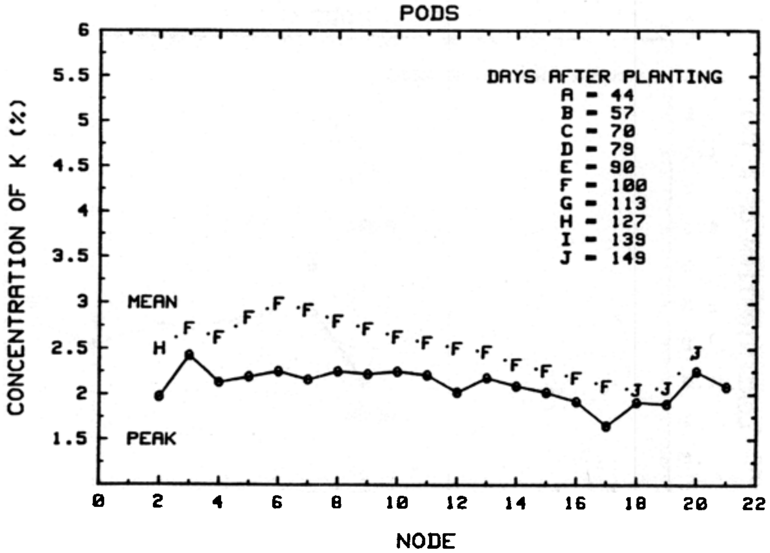

FIG. 29. Pod K% vs Node. Letters are Date of Peak K%.

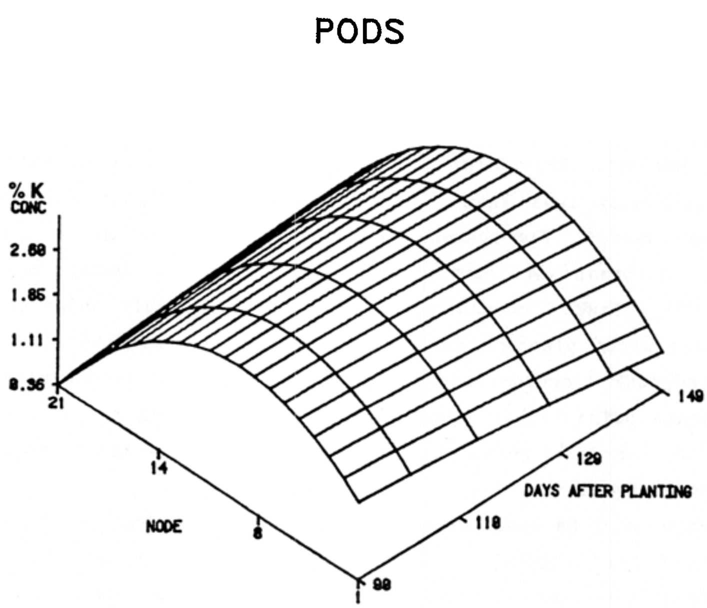

FIG. 30. Pod K% Statistical Response Surface for Node and Time

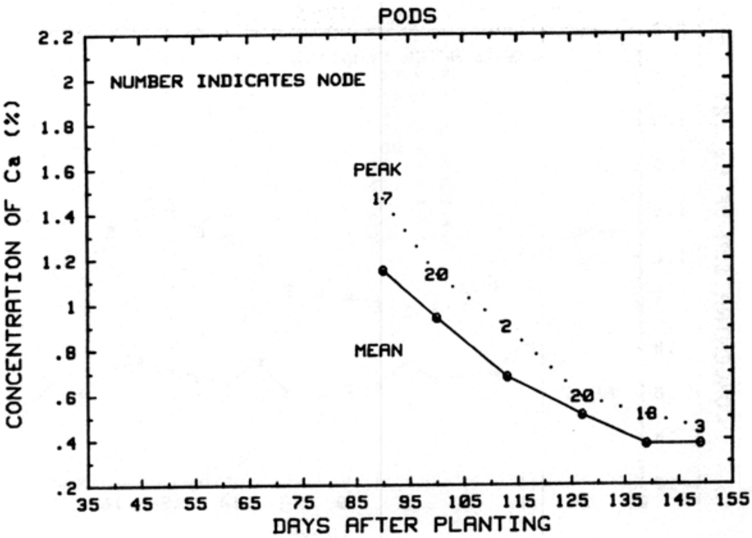

FIG. 31 Pod Ca% vs Time. Numbers are Node of Peak Ca%.

Seasonal average Ca concentrations in pods (Fig. 32) were nearly unaffected by nodal position and were almost constant at about 0.7%. Peak concentrations at the various nodes came almost exclusively from the sampling 90 days after planting and were generally about half a percentage point higher than seasonal mean values. The statistical response surface (Fig. 33) for pod Ca shows higher concentrations early in the season, nearly no effect of nodal position, and a nearly planar surface with lower concentrations later in the season.

Mean nodal Mg concentration in pods (Fig. 34 and Fig. 35) was nearly unaffected by sampling date or nodal position. Peak concentrations were less than 0.1 percentage point more than means whether averaged over nodes or over time. Peak concentrations came almost exclusively from the 90 day after planting sampling (initial sample from pods) and occurred low in the canopy. The statistical response surface of Mg for pods (Fig. 36) shows little or no affect of time on Mg concentration with a slight concentration peak in central nodal

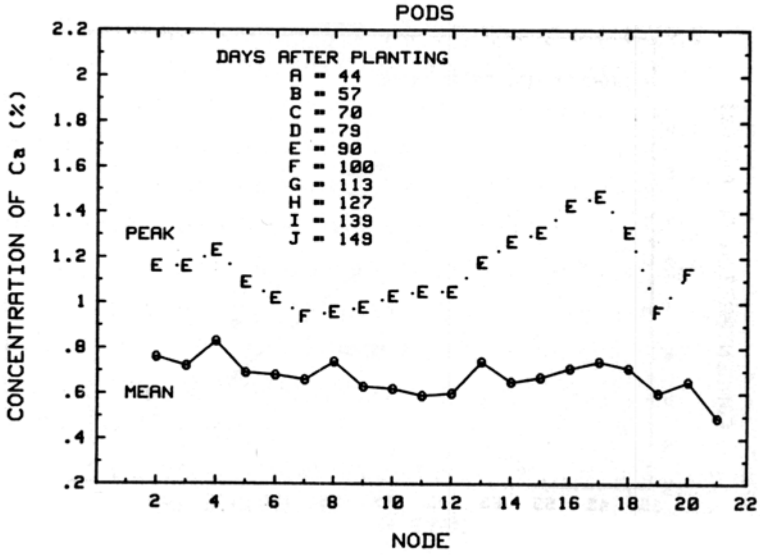

FIG. 32 Pod Ca% vs Node. Letters are Date of Peak Ca%.

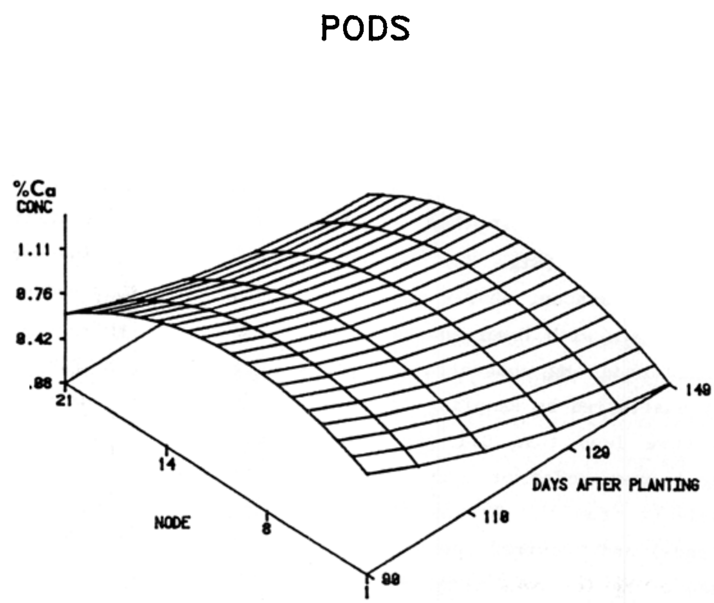

FIG. 33. Pod Ca% Statistical Response Surface for Node and Time

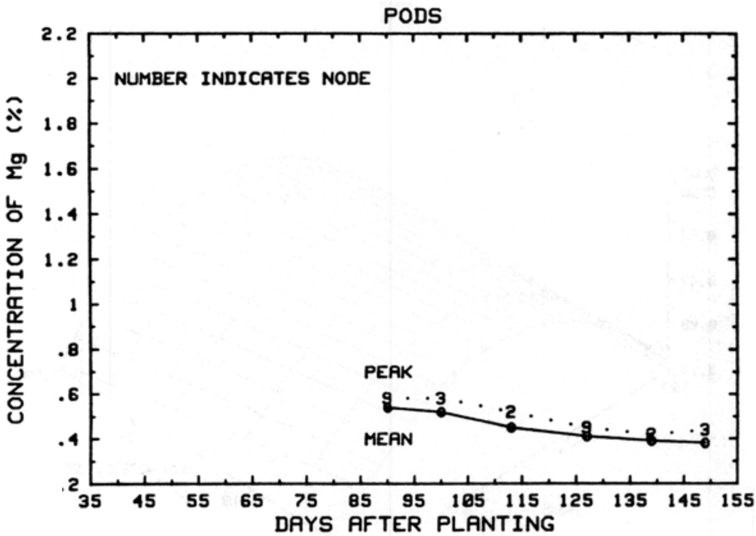

FIG. 34. Pod Mg% vs Time. Numbers are Node of Peak Mg%.

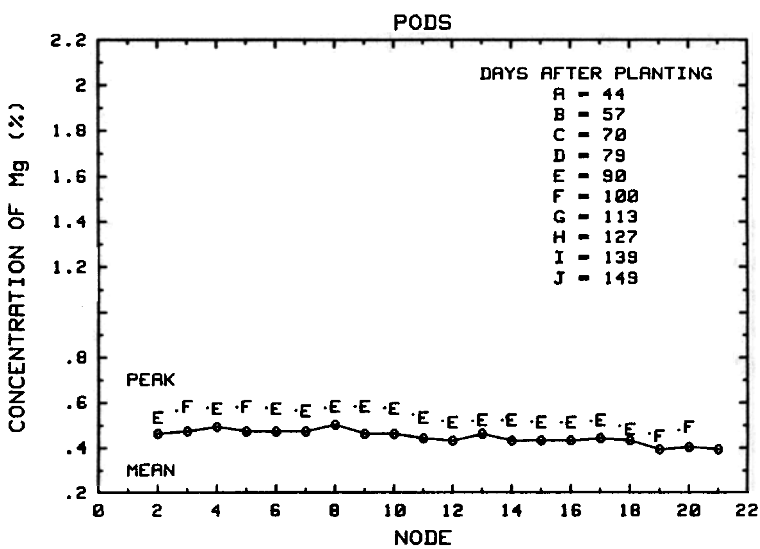

FIG. 35. Pod Mg% vs Node. Letters are Date of Peak Mg%.

PODS

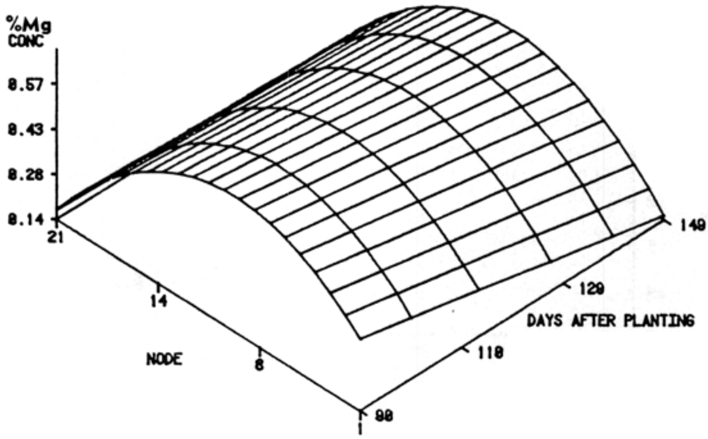

FIG. 36. Pod Mg% Statistical Response Surface for Node and Time

positions. Estimation of the variance of K, Ca, and Mg concentrations in pods was impeded by the extensive pooling of samples needed in early pod fill to facilitate nodally segmented partioning of the data. Lack of uniformity in pod size related to canopy position aggravated this problem, in some instances with upper nodal positions having had insufficient tissue on some dates in one or more replications for separate analysis. Therefore, LSD's and CV's could be calculated for only a few data and no meaningful presentation in tabular form is possible.

CONCLUSIONS

In excess of 10,000 individual cation analyses are summarized in the preceding pages. These data show that cation concentrations of a growing soybean crop are significantly affected by plant part, cation species, plant age, and morphologically-derived position within the canopy. Nodal and temporal mean concentrations of K and Ca generally varied considerably due to plant age and nodal position, respectively, in all plant parts. Mean concentrations of Mg were largely unaffected by either plant age or nodal position. Peak concentrations of Ca and Mg are generally associated with upper nodal positions. As new nodes are initiated, the expanding tissue represents an identifiable sink for K. Of importance in plant analysis is the observation that mean concentrations of elements in all four plant parts can vary by two fold or more depending upon plant age and nodal composition of the sample.

It is doubtful that a single sampling in time or space could be used to accurately extrapolate the cation nutrient concentration patterns derived here empirically. These patterns are important, however, as a detailed examination of how concentration patterns exist in reality. As such, the authors feel these data provide a baseline for understanding nutrient relationships in determinate soybean. These relationships are fundamental to the study of nutritional and physiological processes and to modeling of soybean growth, nutrient accumulation, translocation, and yield.

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APPENDIX TABLE A

Mathematical and Statistical Description of Response Surface Relationships for the Named Parameters using the Equation Form $Y = a + b(node) + c(node)^2 + d(date) + e(date)^2 + f(node)(date)$. Factors Not Significant at the 0.1 Level of Probability are Indicated as "NS" under the Table Entry.

Parameter	Coefficients						Combined
	a	b	c	d	e	f	R^2
Combined wt.	-95.540	7.215	-0.596	2.011	-0.009	0.035	0.83
Stem wt.	-28.418	0.919	-0.110	0.762	-0.003	0.004	0.87
Petiole	-42.768	1.724	-0.136	0.985	-0.004	0.003 NS	0.65
Leaf wt.	-37.898	2.740	-0.185	0.857	-0.005	0.010	0.63
Pod wt.	-42.353 NS	5.173	-0.246	0.071 NS	0.001 NS	0.005 NS	0.72
Stem Pc*	0.645	-0.084	0.003	0.004	0.000018 NS	0.000018 NS	0.68
Petiole	-0.339	0.009 NS	-0.00014 NS	0.013	-0.0001	-0.001	0.52
Leaf Pc	0.397	0.056	0.00020 NS	-0.004	0.00001 NS	-0.0004	0.84
Pod Pc	1.017	-0.056	-0.0004	-0.020	0.00009	0.0007	0.97
NLAI †	-1.382	0.085	0.005	0.030	-0.0002	0.0001	0.72
Internode cm	-7.010	1.152	-0.065	0.147	-0.0007	0.002	0.83
Internode g/cm	0.612 NS	-0.331	0.0026 NS	0.081	-0.0003	0.00012 NS	0.83
Comb. wt.CV ††	61.903	2.087 NS	0.304	-0.5767 NS	0.005	-0.077	0.14
Stem CV	112.448	2.288 NS	0.209	-1.990	0.010	-0.047	0.19
Petiole CV	299.573	-9.134	0.788	-3.525	0.020	-0.097	0.21
Leaf CV	400.220	-8.063 NS	0.766	-6.496	0.039	-0.102	0.26
Pod CV	220.513 NS	-19.681	0.870	-1.032 NS	0.008 NS	-0.040	0.22

* Indicates partition coefficients, as defined by Scott et al. (1983).
† Nodal Leaf Area Index.
†† Coefficients of variation.