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BRAGG SOYBEANS GROWN ON A SOUTHERN COASTAL PLAIN SOIL
IV. SEASONAL CHANGES IN NODAL N AND P CONCENTRATIONS

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ABSTRACT

Determinate soybean [Glycine max (L.) Merr.] has been characterized by few detailed nitrogen and phosphorous partitioning studies. Knowledge of the variation in N and P concentrations with plant part, nodal position, and plant age is needed for a better understanding of plant functions. In this field study, 'Bragg' soybean was 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 N concentrations were 3.1, 2.8, 5.8, and 5.4% for stem internodes, petioles (+branches), leaf blades, and pods, respectively. Maximum observed P concentrations were 0.34, 0.48, 0.78, and 0.52 for the same respective plant parts. Nodal and temporal mean N and P concentrations varied considerably with plant age and nodal position in all plant parts. These data show that mean N and P concentrations in all four plant parts can vary several fold, depending upon plant age and nodal position for the sample. This suggests caution should be exercised in tissue sampling and interpretation of plant analysis. Concentrations of N and P generally decreased with time for stem internode, petioles (+branches), and leaf blades, but increased with time for pods. Except for N concentration in stem internodes, which increases with internode number, the N and P concentrations remain nearly constant throughout the growing season. The relationships provide insight for developing accurate plant models depicting N and P concentrations and translocations over time and among plant parts in determinate soybean.

INTRODUCTION

This paper is the fourth in a series that describes in great detail nodal growth, dry matter distribution, and nutrient uptake for a determinate soybean [*Glycine max* (L.) Merr.] cultivar. Field management practices, weather patterns, growth stages, leaf area, plant height, weight/length of stem internodes, crop growth rates, relative growth rates, net assimilation rates, leaf area ratios, specific leaf areas, and leaf weight ratio ares presented in the first paper[19]. Equally detailed information on concentrations of K, Ca, Mg, Fe, Zn and Mn are presented in the second[21], and third paper[20]. Each paper provides a comprehensive presentation of statistical variability as influenced by time of sampling or nodal position for each plant part.

Effects of plant age and/or morphology on seasonal changes in elemental concentrations and partitioning within field-grown soybean are not thoroughly documented, particularly on a nodally segmented basis. Furthermore, the majority of partitioning studies that have been conducted have evaluated indeterminate cultivars[4,15,9,14,8,2] rather than determinate cultivars[23,10,3]. Analysis on a nodal basis, though very labor intensive, allows for estimates of remobilization from vegetative to reproductive plant fractions[12,6,25,13]. Nodal analysis can also be used to validate nutrient modeling concepts[16] and to better understand changes in nutrient concentrations within the plant for diagnostic purposes.

The purpose of this paper is to characterize N and P accumulation and distribution for a determinate soybean cultivar on a nodal basis. Nitrogen and P concentrations are discussed together because N stress has been shown to increase P concentrations[24].

METHODS AND MATERIALS

A detailed description of field layout and operations, experimental design, and plant sampling has been presented by Scott et al.[19]. 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[5], was equipped with a combination drainage-subirrigation system. Soil water status was monitored and regulated with tensiometers placed within and between soybean rows.

A determinate soybean cultivar, 'Bragg' (maturity group VII) was grown. Preplant fertilizer providing 0-30-56 kg ha^{-1} N-P-K was applied based upon South Carolina soil test recommendations. Weed and insect control were achieved with appropriate chemical applications and timely cultivation. Soybean was conventionally planted to a stand of 220,000 plants ha^{-1} on 23 May in rows 1-m wide and 75-m long within the 1-ha field. Mean seed yield for this study was 2.2 Mg ha^{-1}. 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[17,18,16]. Nodes were numbered and growth stages identified using the conventions of Fehr et al.[7]. Each numbered internodal main stem segment was made up of the identified node ($node_n$) and internodal tissue between it and the next lowest numbered node ($node_{n-1}$). Throughout the season the partitioned dry matter components were oven dried at 60C, weighed, ground to pass a 0.5 mm stainless steel screen, digested with sulfuric acid and hydrogen peroxide, and analyzed for N using industrial method 334-74 W/B[22]. Ammonium molybdate-ammonium vanadate reagents were used for phosphorous by the method of Jackson[11]. Analysis of N and P were verified periodically using NBS standard tissues.

Water pH and prefertilization Mehlich 1 extractable P, K, Ca, and Mg concentrations in mg Kg^{-1} at the experimental site were 6.1, 73, 105, 68, and 413 for the Ap horizon; 5.8, 12, 64, 32, and 200 for the E horizon (A_2); and 4.8, 1, 144, 94, and 353 for the B_t horizon, respectively. Micronutrient concentrations in the Ap were "adequate" for soybean production by Clemson University soil test results.

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, locations x replication and location x date x replication were used to test the location and time-integrated sources of variation respectively. For development of statistical response surfaces, dependent variables were regressed over time and nodal position.

RESULTS AND DISCUSSION

Mean N and P concentration data are grouped and reported sequentially for stem internode, petioles + branches, leaf blades, and pods (pod walls + beans). The data are illustrated by nodal origin (internodes in the case of stems) to show how sampling position influences plant nutrient concentration, by date to show effect of sampling time, and in response surfaces to show the combined statistical effect of those two parameters. Regression equations provide information useful for development of nodally segmented translocation models, such as Sallam et al.[16], developed for K. The polynomial relationships for calculating N and P statistical response surfaces are presented in Table 1. Polynomial relationships for calculating statistical response surfaces of growth parameters and K, Ca, Mg, Fe, Zn, and Mn concentrations were reported earlier [19,21,20]. The LSD's and CV's present previously undetermined variances caused by nodal sampling position and time after planting for N and P concentrations.

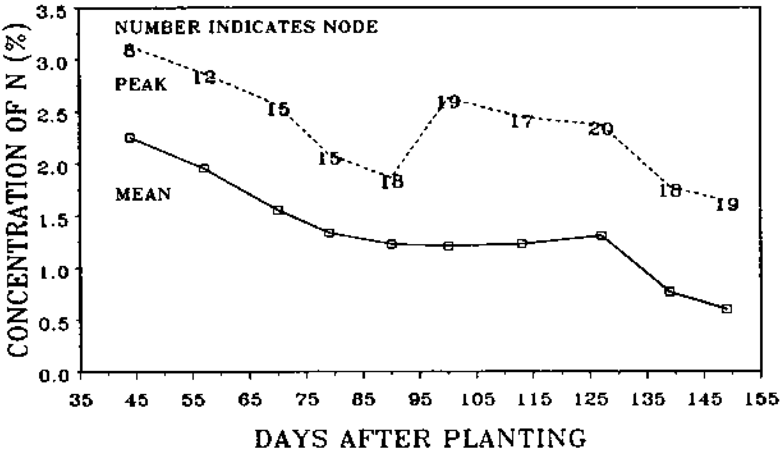
Stem Internodes

Elemental concentrations are presented in Figures 1-4. Maximum observed concentrations of N and P in internode were 3.13 and 0.34%, respectively, both measured at internode 8 and collected 44 days after planting. Mean internode N concentration (Fig. 1a) declined nearly linearly from 2.25% at the V8 growth stage on day 44 to about 1.25% at the time of pod set (R2 to R4) 79-90 days after planting, remained constant during the pod fill period and then declined to 0.60% by the end of pod fill (R8) on day 149. When analyzed by nodal position (Fig. 1b), mean internode N concentration rose linearly with node number from 0.77% at node 1 to 2.00% at node 19. Peak N concentration (Fig. 1a) fell linearly from 3.13% to 1.87% from day 44 to day 90. On day 100 at growth stage R5 the peak rose to 2.63% and again fell linearly to 1.64% on day 149. Throughout the season peak N concentrations were associated with the upper

TABLE 1.--Mathematical and statistical description of response surface relationships for the named parameters using the equation $Y = a + b\ (\text{node}) + c\ (\text{node})^2 + d\ (\text{date}) + e\ (\text{date})^2 + f\ (\text{node})\ (\text{date})$. Factors not significant at the 0.1 level of probability are indicated as "NS" under the table entry.

Fig No.	Element	Coefficients						Combined R^2
		a	b	c	d	e	f	
					Stem internode			
2	N	1.062	0.007 NS	-0.008	0.010 NS	-0.000158	0.00162	0.33
4	P	0.058 NS	0.00008 NS	-0.00078	0.0032	-0.000025	0.00012	0.50
					Petiole + Branches			
6	N	0.115 NS	0.066	-0.009	0.030	-0.000210	0.000966	0.43
8	P	-0.025 NS	0.011	-0.0012	0.0045	-0.000029	0.000081	0.39
					Leaf Blade			
10	N	-5.065	0.216	-0.022	0.189	-0.0011	0.0020	0.53
12	P	0.080 NS	0.016	-0.0017	0.0076	-0.000050	0.000141	0.42
					Pod			
14	N	-12.032	0.480	-0.026	0.203	-0.000754	0.000615 NS	0.36
16	P	-0.700 NS	0.048	-0.0024	0.014	-0.000053 NS	0.000005 NS	0.26

(a) INTERNODES



(b) INTERNODES

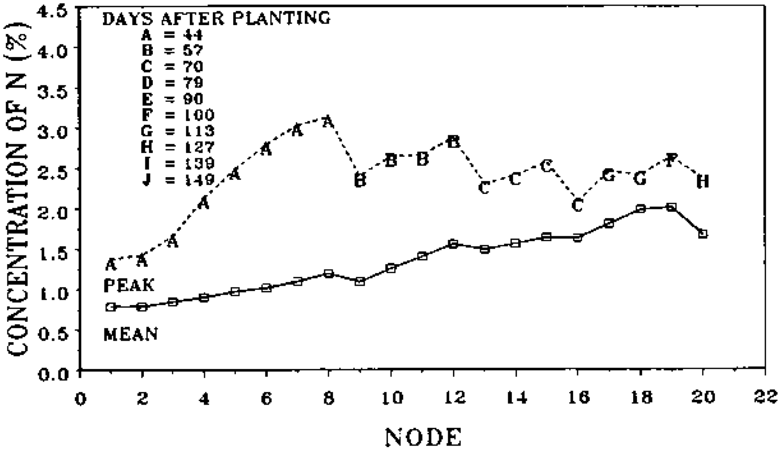


Fig 1. Internode N % with node or date of peak %.

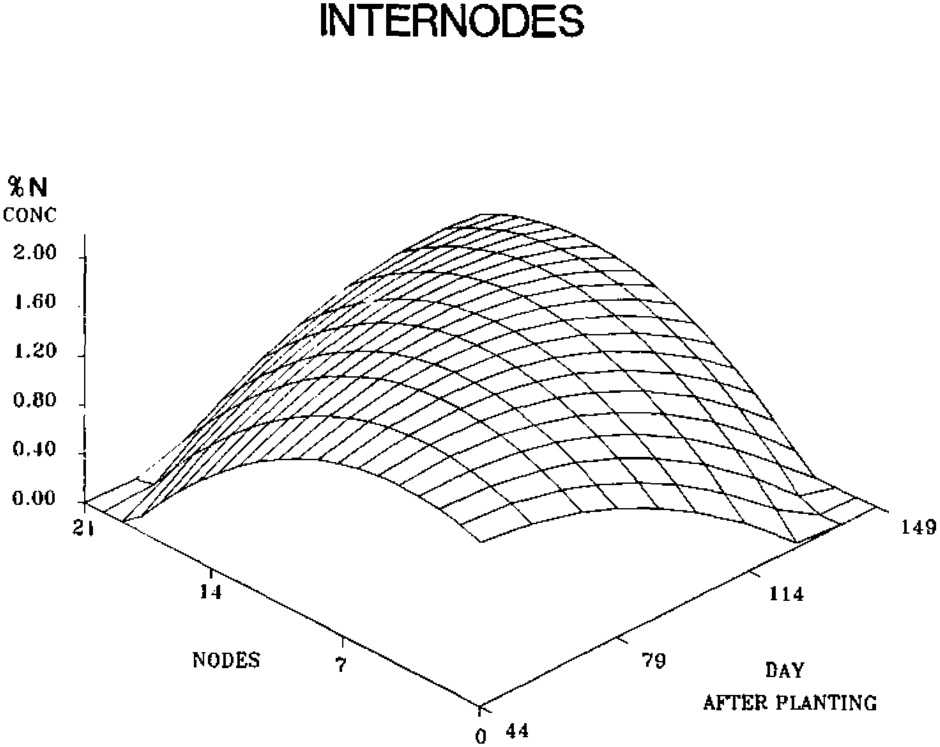
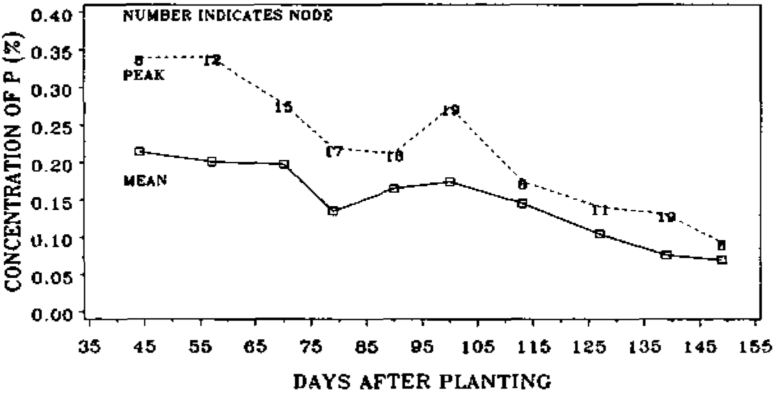


Fig. 2. Internode N % with response surface for node vs time.

nodal positions for a given sampling date. Peak N concentrations varied with internode number (Fig. 1b) through the season but generally rose from the low value of 1.37% at internode 1 to a plateau around 2.5% above internode 6. At all nodal positions peak N concentrations were generally associated with the earliest sampling dates for the particular node. The statistical response surface of N (Fig. 2) showed mean internode concentration nearly constant over nodal position and time once node initiation had occurred.

Mean internode P concentrations (Fig. 3a) declined nearly linearly from 0.21% to 0.07% from day 44 to day 149. A decrease in concentration occurred at R2 on day 79. When analyzed by nodal

(a) INTERNODES



(b) INTERNODES

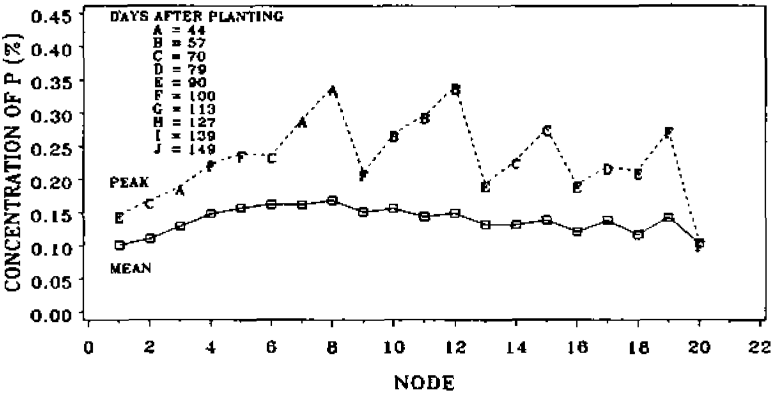


Fig. 3. Internode P % with node or date of peak %.

position (Fig. 3b) mean internode P concentration was nearly constant around the mean of 0.14%, though slightly lower at the highest and lowest nodal positions. Peak P concentrations fell nearly linearly with time (Fig. 3a) from a high of 0.34% on days 44 and 57 to a low of 0.08% on day 149. A brief rise in concentration occurred at R5 on day 100. Until the late reproductive stages, concentration peaks occurred in the uppermost nodal positions for those sampling dates but began to be associated with lower nodal positions beginning at stage R6 on day 113. Peak P concentrations varied with internode number (Fig. 3b) around a plateau value of approximately 0.23%. Peak P concentrations at all nodal positions tended to occur early in the growing season (before day 100, or stage R5). The statistical response surface (Fig. 4) indicates a tendency for mean internode P concentrations to be near their maximum at mid season and at central nodal positions.

Least significant differences and coefficients of variation for mean concentrations of stem internodes 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 N and P in Tables 2 and 3. These data can help assess the anticipated variation associated with collecting plant tissue from a particular nodal position or at a particular sampling date (or growth stage). Missing data resulted from the need in some instances to pool tissue samples from more than one replication for elemental analysis or absence of tissue in some positions or dates.

The nodal data (Table 2) show that variance of stem internode N and P concentrations fluctuate somewhat irregularly with sampling date. This occurs because of changing nodal concentrations and an increasing number of nodes as the season progressed. There is a slight tendency for greater variance at later sampling dates when redistribution and translocation of nutrients result in more complicated source-sink relationships. The temporal data (Table 3) show that variance of stem internode N and P concentrations fluctuate with sampling date composition somewhat irregularly with nodal position. There is a slight tendency for greater variance at

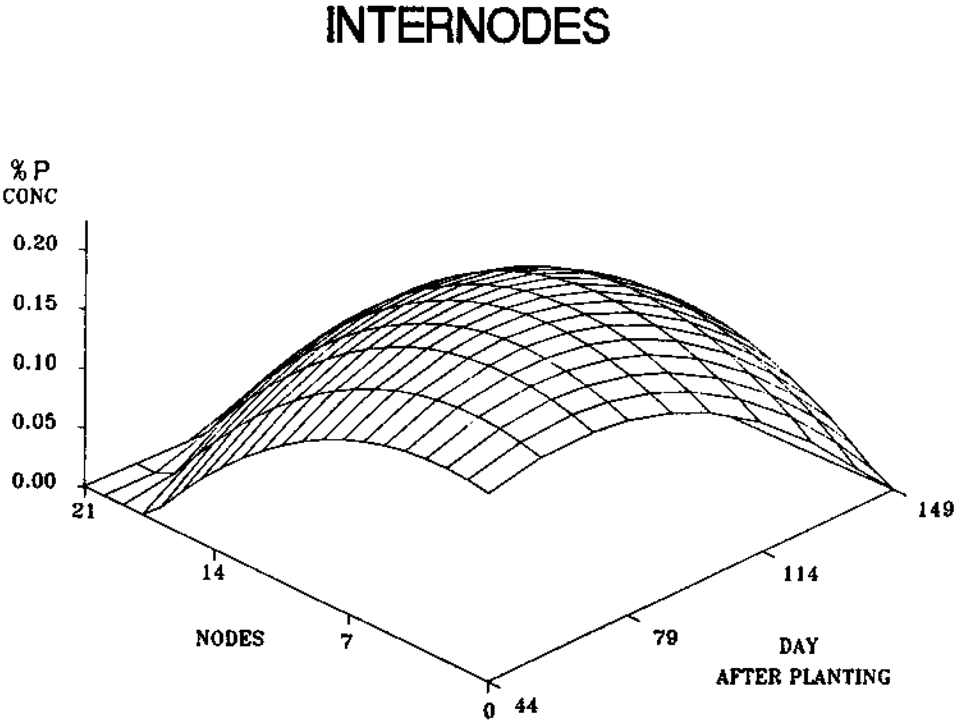


Fig. 4. Internode P % response surface for node vs time.

TABLE 2.--Nodal concentration (%) variance of stem internodes at selected sampling dates.

Days after planting	N		P	
	LSD_n	CV_n	LSD_n	CV_n
44	0.17	7.20	0.02	8.96
57	0.22	10.00	0.03	13.75
70	0.21	14.33	0.04	20.10
79	0.20	16.55	0.04	33.58
90	0.22	21.59	0.04	27.61
100	0.16	13.36	0.06	27.61
113	0.15	8.12	0.04	15.80
127	0.15	7.93	0.05	35.85
139	0.30	27.60	0.03	28.05
149	0.21	25.36	0.03	24.09

TABLE 3.--Temporal concentration (%) variance of stem internodes at each nodal position.

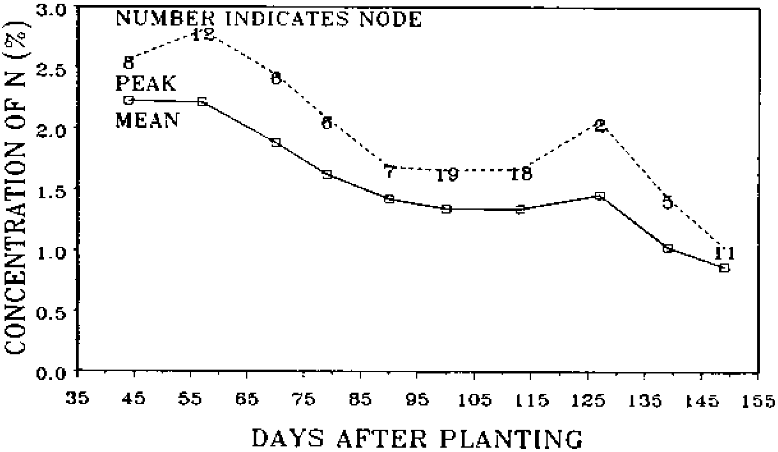
Node	N		P	
	LSD_t	CV_t	LSD_t	CV_t
1	0.08	8.30	0.04	33.52
2	0.07	7.79	0.04	29.43
3	0.22	22.96	0.04	26.01
4	0.10	9.36	0.06	32.86
5	0.13	11.74	0.03	15.08
6	0.13	10.92	0.04	18.94
7	0.14	11.72	0.04	20.69
8	0.20	14.35	0.04	22.04
9	0.24	18.16	0.04	21.18
10	0.28	18.31	0.04	20.63
11	0.34	18.72	0.04	22.10
12	0.43	19.26	0.07	35.48
13	0.29	15.27	0.04	26.63
14	0.31	15.36	0.05	31.37
15	0.24	9.70	0.07	34.35
16	0.28	13.32	0.05	30.90
17	0.44	15.14	0.07	30.65
18	0.66	14.53	0.09	33.94
19	0.64	1.84	1.50	64.84

central nodal positions for N and for upper nodal positions for P. Generally, time-related P variances were nearly double the N variances. Central nodal positions accounted for the largest proportion of pods set, whereas upper nodal positions are associated with more juvenile tissue and fewer sampling dates.

Petioles (+ Branches)

Concentration data for the petiole (+branches) component are presented in Figs. 5-8. Maximum observed N and P concentrations in petioles (+branches) were 2.81 and 0.48%, respectively, both measured at node 12 and collected 57 days after planting. Mean petiole (+branches) N concentration (Fig. 5a) declined throughout

(a) PETIOLES (+ BRANCHES)



(b) PETIOLES (+ BRANCHES)

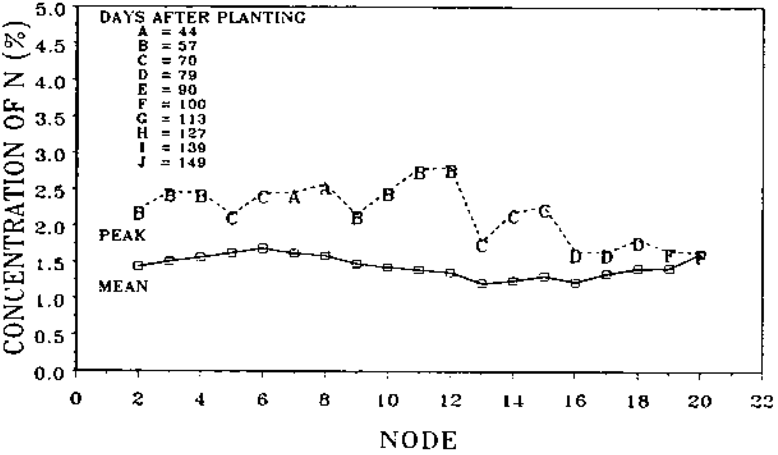


Fig. 5. Petiole (+branches) N % with node or date of peak %.

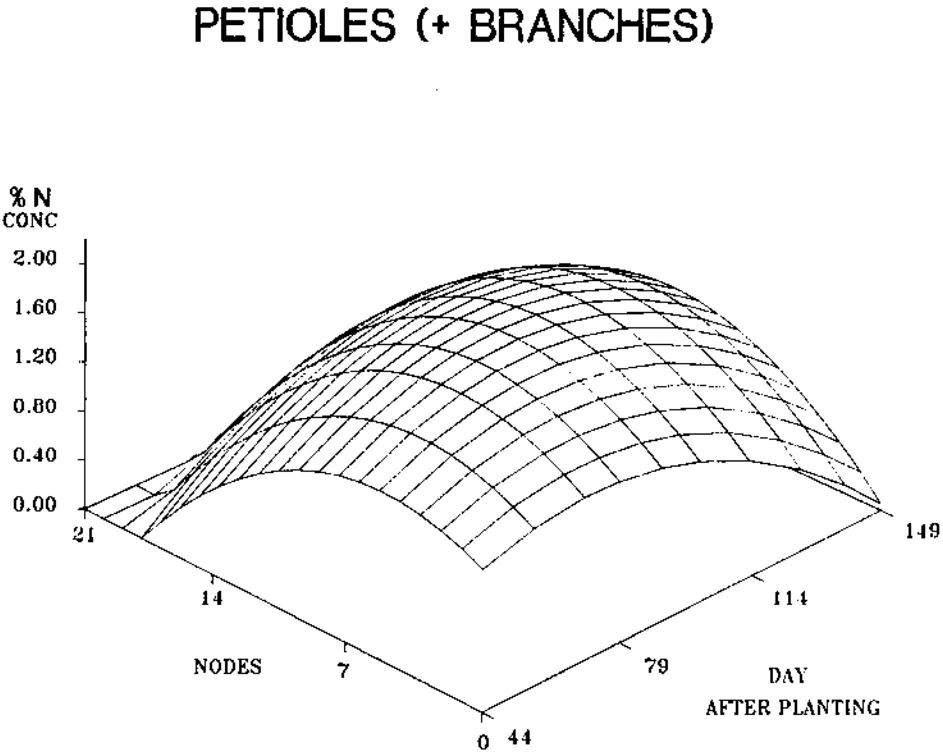
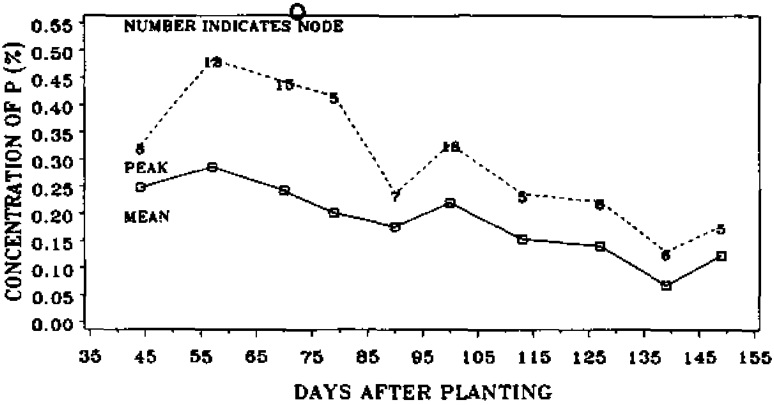


Fig. 6. Petiole (+branches) N % response surface for node vs time.

the season from an initial value of 2.25% to a low of 0.87% with a plateau from day 79 to day 127 (R2 to R7) around 1.5%. When analyzed by nodal position (Fig. 5b) mean petiole (+branches) N concentration remained nearly constant for all nodal positions around the overall mean value of 1.45%. Peak N concentration (Fig. 5a) fell during the vegetative period from a high of 2.81% on day 57 (V10) to a plateau around 1.7% from day 90 to 113 (R4 to R6) increasing to 2.06% on day 127 (R7) and falling to 1.03% by the end of the season. Peak N concentrations (Fig. 5a) were associated with varying nodal positions throughout the season. At all nodal positions (Fig. 5b) peak N concentrations were associated with early sampling from a particular node with a plateau value of about 2.0%.

(a) PETIOLES (+ BRANCHES)



(b) PETIOLES (+ BRANCHES)

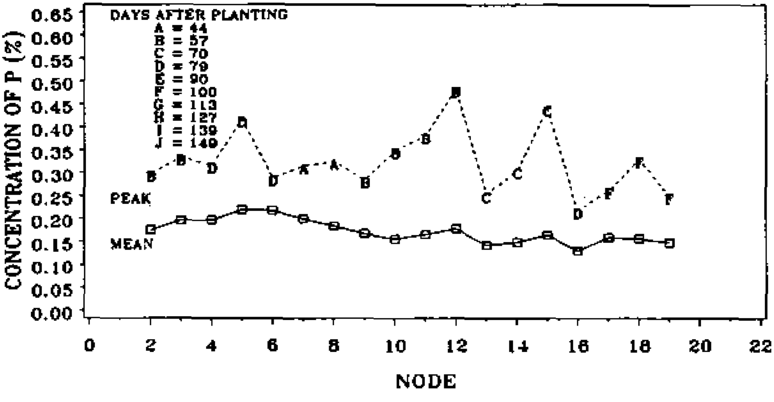


Fig. 7. Petiole (+branches) P % with node or date of peak %.

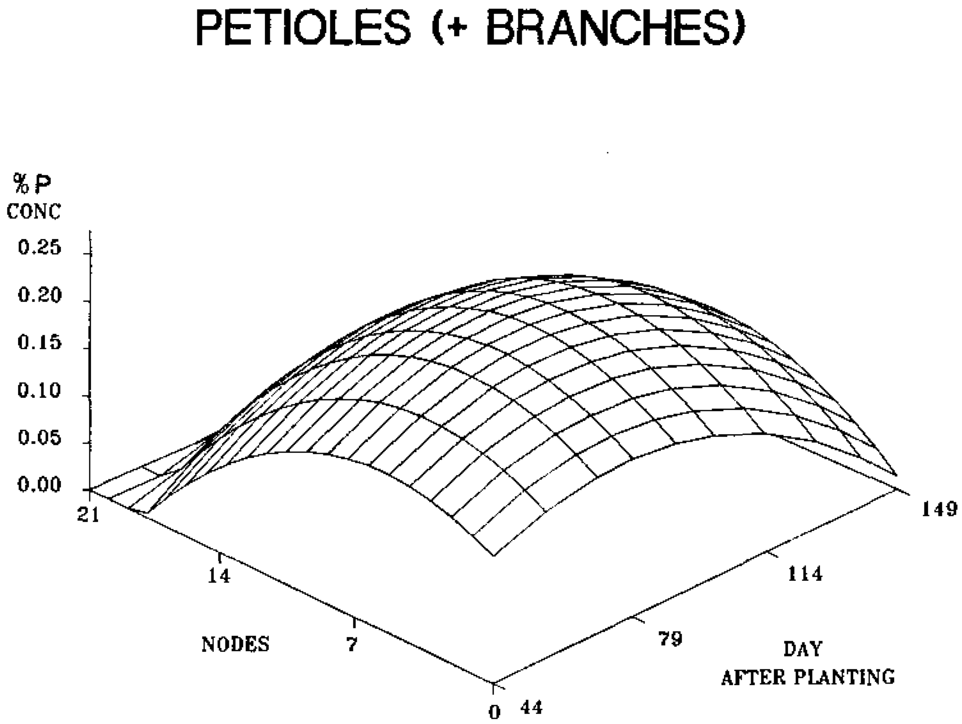


Fig. 8. Petiole (+branches) P % response surface for node vs time.

The statistical response surface for N (Fig. 6) showed higher concentrations for central nodal positions and late season sampling dates.

Mean petiole (+branches) P concentrations (Fig. 7a) declined nearly linearly from the early season high value of 0.30% on day 57 (V10) to the late season low value of 0.07% on day 139 (R7.5). When analyzed by nodal position (Fig. 7b) mean petiole (+branches) P concentration is nearly constant near the overall mean concentration of 0.18%. Peak P concentrations dropped nearly linearly from the early season (Fig. 7a) high value of 0.48% on day 57 (V10) to a seasonal low value of 0.13% on day 139 (R7.5) near the end of the season. Concentrations fell sharply on sampling day 90 (R4) but returned to the baseline on day 100 (R5). Nodal origin of peak

TABLE 4.--Nodal concentration (%) variance of petiole (+branches) at selected sampling dates.

Days after planting	N		P	
	LSD_n	CV_n	LSD_n	CV_n
44	0.25	5.77	0.03	7.32
57	0.32	9.79	0.05	12.22
70	0.24	10.76	0.05	19.13
79	0.31	16.15	0.06	32.34
90	0.30	20.51	0.06	31.61
100	0.16	7.45	0.07	20.20
113	0.22	10.36	0.07	28.30
127	0.25	10.99	0.10	48.57
139	0.25	15.58	0.05	47.78
149	0.30	21.13	0.08	37.15

TABLE 5.--Temporal concentration (%) variance of petioles (+branches) at each nodal position.

Node	N		P	
	LSD_t	CV_t	LSD_t	CV_t
1	-	-	-	-
2	0.70	25.57	0.13	38.72
3	0.25	11.66	0.11	36.08
4	0.37	17.74	0.07	24.84
5	0.42	19.98	0.07	23.87
6	0.31	14.63	0.07	26.60
7	0.30	14.62	0.06	24.69
8	0.36	15.29	0.07	25.76
9	0.29	15.93	0.06	28.28
10	0.26	14.85	0.07	40.08
11	0.20	11.46	0.05	28.71
12	0.28	14.57	0.07	30.25
13	0.23	14.33	0.05	27.82
14	0.20	11.96	0.05	23.61
15	0.24	11.89	0.08	37.52
16	0.20	11.08	0.05	25.92
17	0.23	9.65	0.08	28.16
18	0.29	9.18	0.05	14.16
19	0.53	6.74	1.15	16.86

concentrations was variable but was associated with higher nodes early in the season and lower nodes late in the season. Peak P concentrations varied with nodal origin of petioles (+branches) (Fig. 7b) and were generally associated with earlier sampling dates. The statistical response surface (Fig. 8) indicates a tendency for higher mean concentrations to occur at mid-season and central nodal positions.

Least significant differences and coefficients of variation for mean concentrations of petioles (+branches) are presented in Tables 4 and 5 for nodal sources of variance (LSD_n and CV_n, respectively) and temporal sources of variance (LSD_t and CV_t, respectively) for N and P. Variance of N rose from low to higher levels between the V8 and R4 growth stages (days 44 to 90) and again between R5 and R8 (days 100 to 149) and generally decreased with higher nodal positions. Variance of P generally increased with later sampling dates and growth stages but was nearly unaffected by nodal position and was consistently higher than N variances.

Leaf Blades

Concentration data for N and P in leaf blades are presented in Figs. 9-12. Maximum observed concentrations of N and P were 5.76 and 0.78%, respectively, both sampled 57 days after planting and were found at nodes 9 and 12, respectively. Over time (Fig. 9a) mean leaf blade N concentration fell nearly linearly from its peak of 5.04% on day 57 (V10) to its seasonal low of 2.18% on day 149 with a brief plateau of concentrations on dates 113 and 127 (R6 and R7) around a value of 4.0%. When analyzed by nodal position (Fig. 9b) mean leaf blade % N was nearly constant for all nodal positions at the overall mean concentration of 4.05%. Peak % N of leaf blades (Fig. 9a) fell nearly linearly from the seasonal high value of 5.76% on day 57 (V10) to the seasonal low value of 2.55% on day 149 (R8). The node of peak % N varied with sampling date through the season. Peak N concentrations were generally higher for mid-canopy nodal positions (Fig. 9b) with a slight dip in % N centered at node 12.

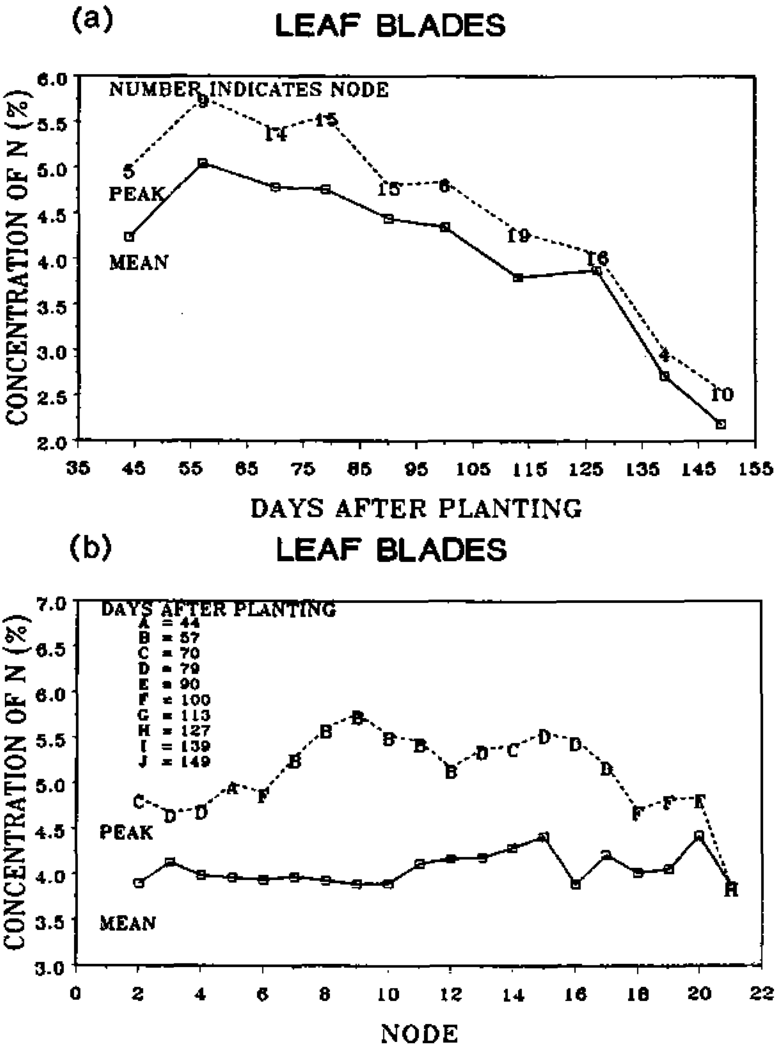


Fig. 9. Leaf blade N % with node or date of peak %.

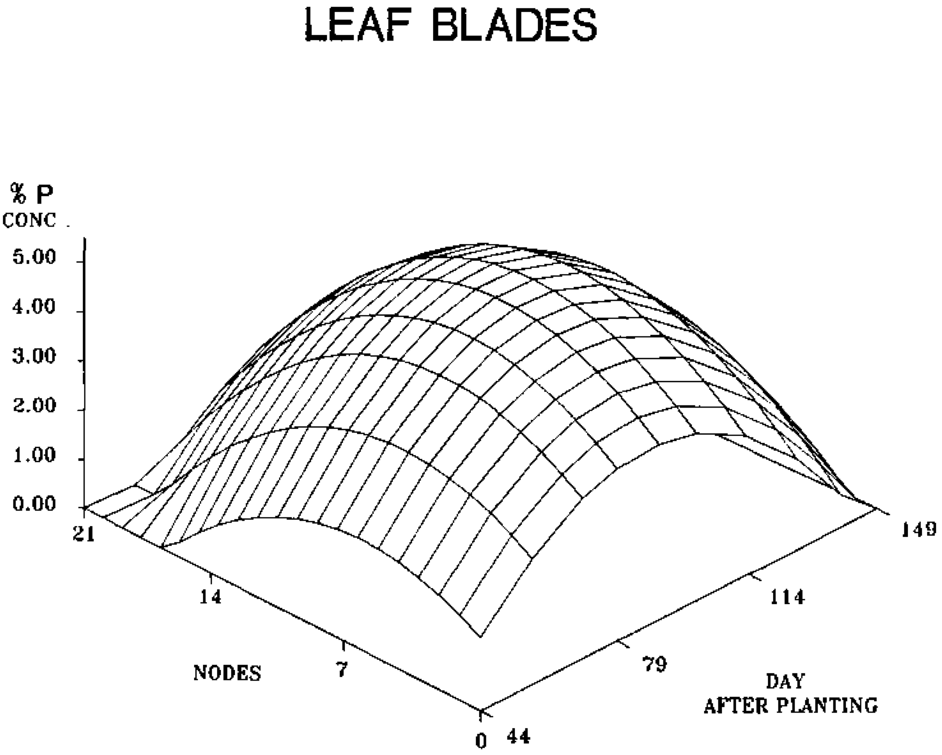
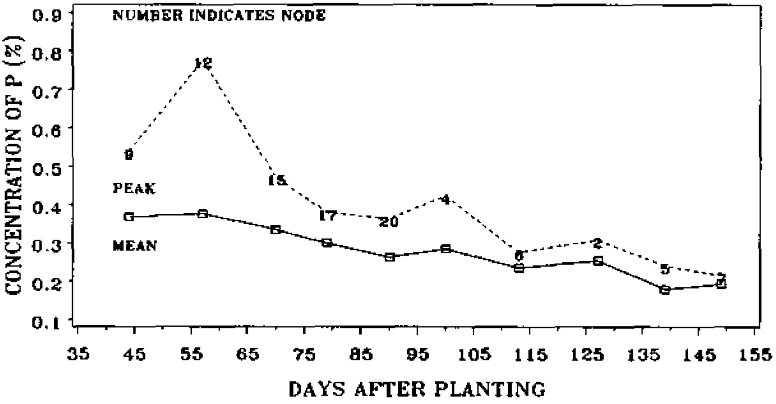


Fig. 10. Leaf blade N % response surface for node vs time.

Peak N concentrations at all nodal positions were usually associated with the first half of the growing season. The response surface (Fig. 10) shows a tendency for the highest leaf blade % N to occur at central nodal positions and at mid-season.

Over time, mean leaf blade P concentration (Fig. 11a) fell linearly from the seasonal high value of 0.38% on day 57 (V10) to the seasonal low value of 0.18% on day 139 (R7.5). When analyzed by nodal position (Fig. 11b) mean leaf blade P concentration remained nearly constant for all nodal positions at the overall mean concentration of 0.27%. Peak leaf blade P concentration (Fig. 11a) fell nearly linearly from the first sampling date (day 44, V8) concentration of 0.54% to the lowest value of 0.22% at 149 days

(a) LEAF BLADES



(b) LEAF BLADES

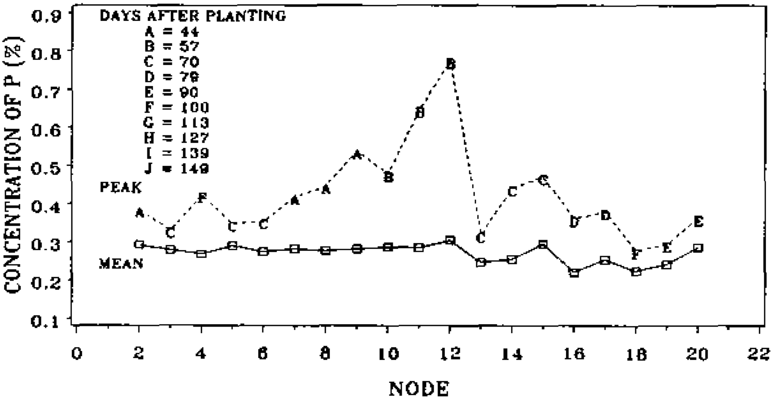


Fig. 11. Leaf blade P % with node or date of peak %.

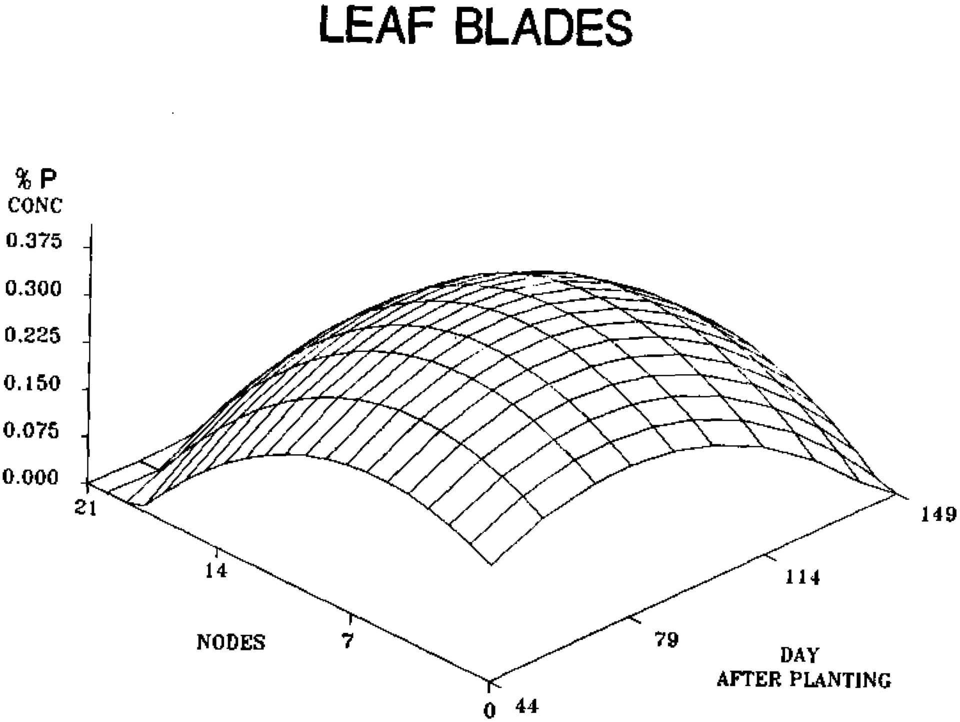


Fig. 12. Leaf blade P % response surface for node vs time.

after planting (R8), except for a pronounced peak on day 57 (V10). Peak P concentrations were from upper nodal positions early in the growing season and from lower nodal positions later in the growing season. Peak leaf blade concentrations (Fig. 11b) were highest at mid-canopy (0.78% at node 12) and were generally associated with early sampling dates for the particular node. The statistical response surface (Fig. 12) showed a tendency for highest mean P leaf blade concentrations at mid-season and central nodal positions.

Least significant differences and coefficients of variation for mean concentrations of leaf blades are presented in Tables 6 and 7 for nodal sources of variance (LSD_n and CV_n, respectively) and temporal sources of variance (LSD_t and CV_t, respectively) for N and P. Variance of N was somewhat lower for later sampling dates (Table

TABLE 6.--Nodal concentration (%) variance of leaf blades at selected sampling dates.

Days after planting	N		P	
	LSD_n	CV_n	LSD_n	CV_n
44	0.70	8.11	0.06	10.11
57	0.36	4.87	0.05	11.82
70	0.57	10.94	0.06	16.58
79	0.36	7.33	0.06	18.94
90	0.31	6.62	0.04	16.33
100	0.25	3.62	0.10	22.89
113	0.41	6.93	0.06	16.51
127	0.27	4.40	0.07	17.18
139	0.32	7.90	0.06	20.69
149	0.63	5.14	0.38	11.59

TABLE 7.--Temporal concentration (%) variance of leaf blades at each nodal position.

Node	N		P	
	LSD_t	CV_t	LSD_t	CV_t
1	-	-	-	-
2	0.86	10.35	0.12	20.81
3	0.68	12.52	0.06	15.52
4	0.56	8.94	0.08	20.33
5	0.55	8.92	0.05	14.00
6	0.66	10.34	0.07	18.53
7	0.30	5.42	0.07	16.41
8	0.41	7.50	0.07	17.95
9	0.41	6.61	0.08	19.51
10	0.49	7.96	0.05	15.50
11	0.46	8.77	0.05	16.88
12	0.32	4.79	0.06	16.19
13	0.24	4.46	0.05	17.00
14	0.21	3.71	0.05	15.50
15	0.37	5.66	0.05	11.88
16	0.46	6.42	0.07	18.27
17	0.46	7.54	0.04	11.91
18	0.32	6.27	0.05	13.99
19	0.73	7.06	0.10	15.78

6) but was somewhat erratic for P concentrations. Variance of P was two to three times greater than for N. Variance of N was somewhat lower for higher nodal positions (Table 7) but was erratic for P concentrations. Again P variances were two to three times greater for P than for N leaf blade concentrations.

Pods

Concentration data for N and P in pods (pod walls + seed) are presented in Figs. 13-16. Maximum observed concentrations of N and P were 4.60 and 0.52%, respectively, sampled 149 and 127 days after planting, respectively, and at nodes 18 and 5, respectively. Over time (Fig. 13a) mean N concentration of pods rose linearly from a low value of 2.86%, sampled 90 days after planting (R4) to a high value of 5.07%, sampled 149 days after planting (R8). When analyzed by nodal position (Fig. 13b) mean pod N concentrations were slightly elevated at the highest and lowest few nodal positions, but otherwise remained nearly constant around the overall mean pod N concentration of 3.85%. Peak N concentration of pods (Fig. 13a) rose linearly in a manner parallel to and not greatly separated from mean values, rising from 3.26% on day 90 (R4) to 5.36% on day 149 (R8). Peak concentrations originated at upper nodes in early and late podfill but at lower nodes in mid podfill (113 and 127 days after planting - R6 and R7). Peak N concentrations of pods were nearly constant for all nodal positions (Fig. 13b) around a value of approximately 5.0%. Nearly all peak N concentrations of pods occurred on the final sampling date, 149 days after planting. The response surface (Fig. 14) shows mean pod N concentrations highest at central nodal positions and increasing for all sampling dates.

Over time, mean pod P concentration (Fig. 15a) rose from a low value of 0.34% at 100 days after planting (R5) to 0.44% at 149 days after planting (R8). When analyzed by nodal position (Fig. 15b) mean pod P concentration fell slightly in an irregular fashion from lower to upper nodal positions but did not depart substantially from the overall mean pod P concentration of 0.39%. Peak pod P

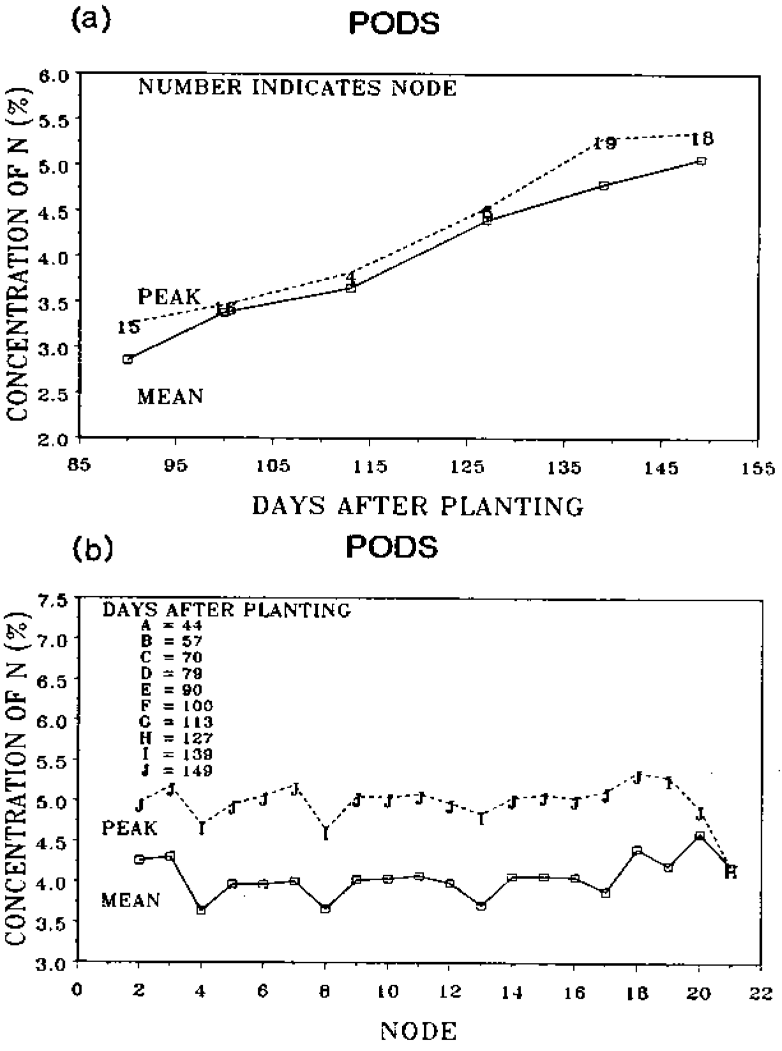


Fig. 13. Pod N % with node or date of peak %.

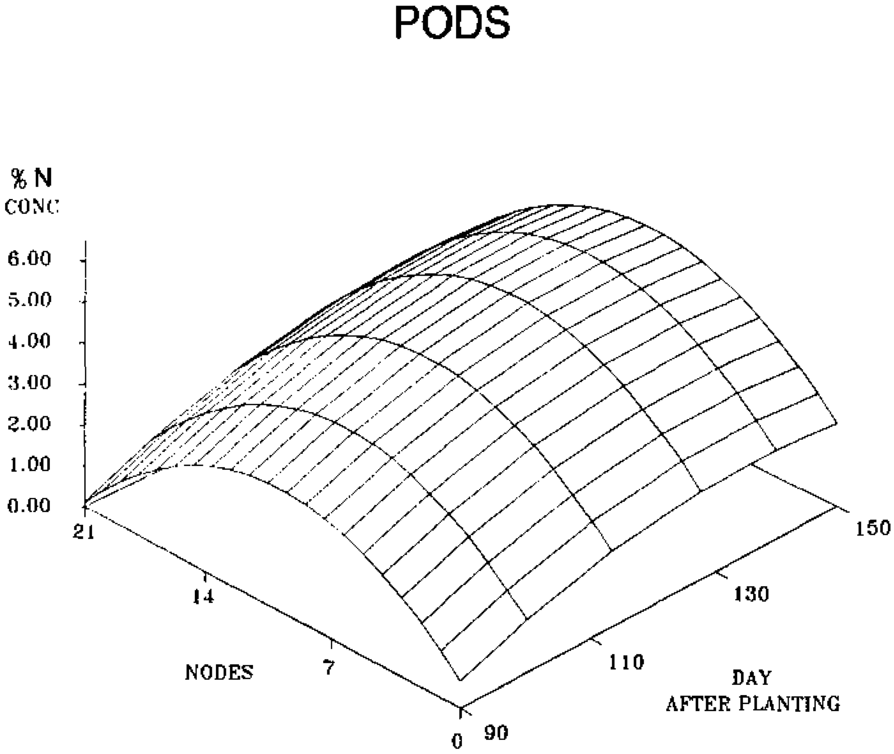
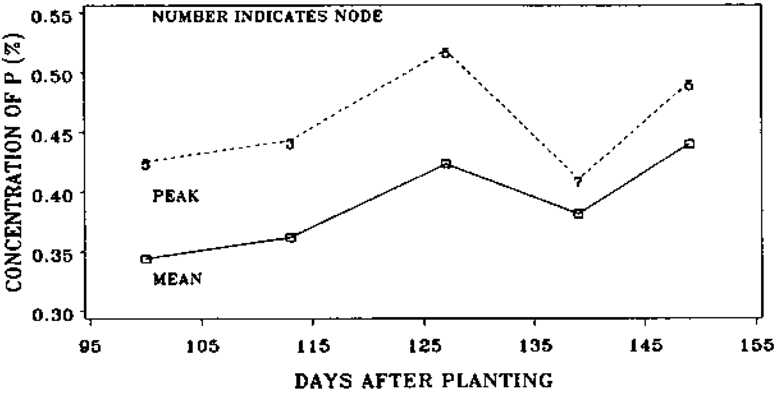


Fig. 14. Pod N % response surface for node vs time.

concentration (Fig. 15a) generally increased through the reproductive period rising from a value of 0.43% at 100 days after planting (R5) to 0.49% at 149 days after planting (R8) with a dip to 0.41% at 139 days after planting (R7.5). Peak pod P concentrations originated at low nodal positions throughout the podfill period. Peak pod P concentrations (Fig. 15b) decreased slightly but irregularly from lower to upper nodal positions but were generally in the approximate range of 0.45%, and for all but one nodal position were associated with the final three sampling dates. The response surface (Fig. 16) shows mean pod P concentration generally highest for central nodal positions and gradually increasing with time.

(a) PODS



(b) PODS

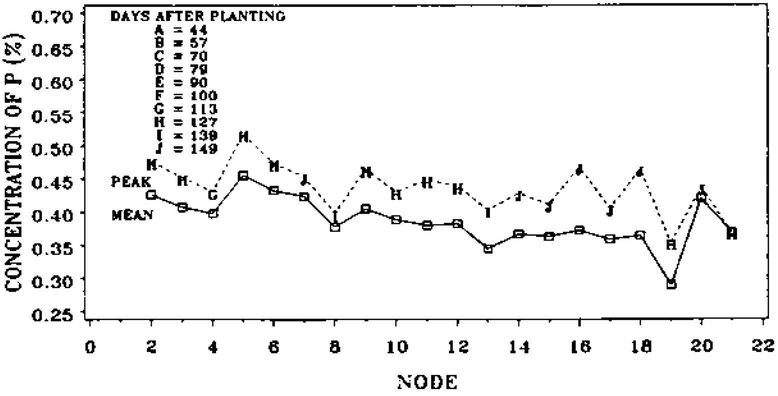


Fig. 15. Pod P % with node or date of peak %.

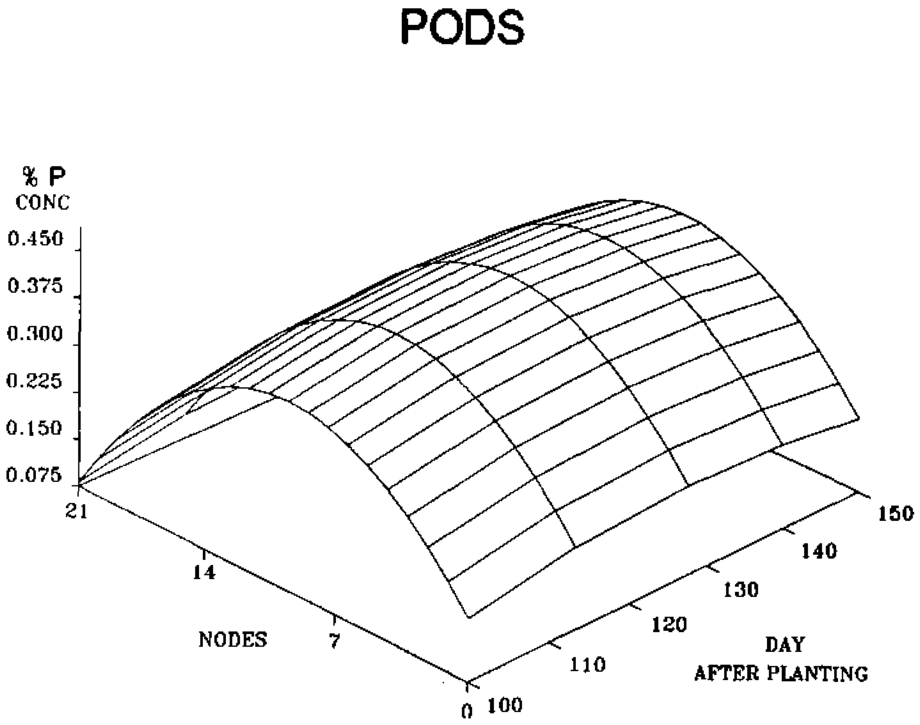


Fig. 16. Pod P % response surface for node vs time.

Least significant differences and coefficients of variation for mean concentrations of pods are presented in Tables 8 and 9 for nodal sources of variance (LSD_n and CV_n, respectively) and temporal sources of variance (LSD_t and CV_t, respectively) for N and P. Variance of N concentration was somewhat greater for early sampling dates and lower nodal positions. Variance of P concentration was somewhat greater for earlier sampling dates, but was variable with respect to nodal position. As for other plant fractions, P concentration variances were two to three times greater than N concentration variances.

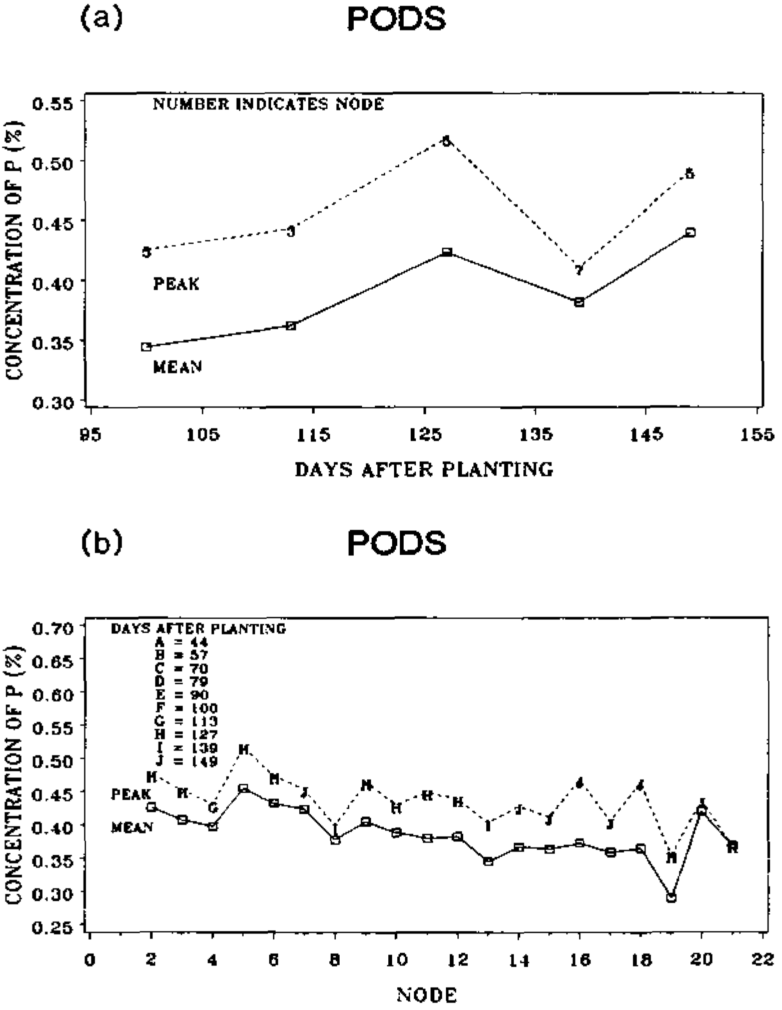


Fig. 15. Pod P % with node or date of peak %.

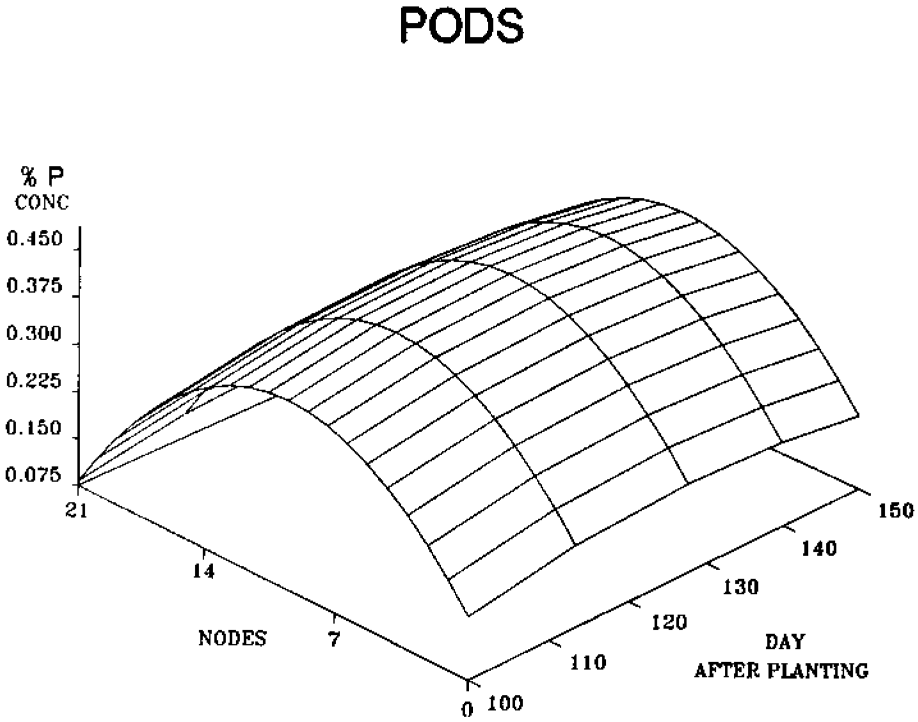


Fig. 16. Pod P % response surface for node vs time.

Least significant differences and coefficients of variation for mean concentrations of pods are presented in Tables 8 and 9 for nodal sources of variance (LSD_n and CV_n, respectively) and temporal sources of variance (LSD_t and CV_t, respectively) for N and P. Variance of N concentration was somewhat greater for early sampling dates and lower nodal positions. Variance of P concentration was somewhat greater for earlier sampling dates, but was variable with respect to nodal position. As for other plant fractions, P concentration variances were two to three times greater than N concentration variances.

TABLE 8.--Nodal concentration (%) variance of pods at selected sampling dates.

Days after planting	N		P	
	LSD$_n$	CV$_n$	LSD$_n$	CV$_n$
90	0.64	10.00	-	-
100	0.15	2.38	0.08	12.77
113	0.27	4.65	0.11	19.64
127	0.21	2.88	0.06	8.86
139	0.25	3.74	0.07	11.27
149	0.26	3.13	0.08	11.12

TABLE 9.--Temporal concentration (%) variance of pods at each nodal position.

Node	N		P	
	LSD$_t$	CV$_t$	LSD$_t$	CV$_t$
1	-	-	-	-
2	0.61	6.61	0.12	16.11
3	0.28	3.02	0.08	9.07
4	0.42	5.98	0.05	6.95
5	0.33	4.50	0.11	14.49
6	0.30	3.78	0.06	9.45
7	0.24	4.08	0.07	10.78
8	0.20	3.41	0.06	9.89
9	0.22	3.60	0.08	12.32
10	0.25	3.80	0.05	8.81
11	0.21	3.16	0.05	8.51
12	0.32	5.25	0.07	12.95
13	0.24	3.66	0.10	18.22
14	0.18	2.66	0.06	11.78
15	0.18	2.65	0.12	22.63
16	0.20	2.48	0.07	11.54
17	0.26	3.35	0.09	12.61
18	0.29	3.62	0.14	20.07
19	0.72	5.37	0.03	2.03

Table 10. Relationship of temporal and nodal N and P linear regressions.

Plant part	Element	------- Equation -------	P	R^2	N/P ratio
(Temporal)					
Stem internode	N	2.5909 - 0.0128806 * (DAP)	**	0.85	-
Stem internode	P	0.2809 - 0.0013733 * (DAP)	**	0.87	9.4
Petiole (+branches)	N	2.7203 - 0.0121874 * (DAP)	**	0.89	-
Petiole (+branches)	P	0.3515 - 0.0017087 * (DAP)	**	0.82	7.1
Leaf blades	N	6.1612 - 0.0221237 * (DAP)	**	0.71	-
Leaf blades	P	0.4552 - 0.0018260 * (DAP)	**	0.92	12.1
Pods	N	-0.4814 - 0.0376636 * (DAP)	**	0.99	-
Pods	P	0.1759 - 0.0017059 * (DAP)	**	0.68	22.1
(Nodal)					
Stem internode	N	0.6561 - 0.06389356 * (DAP)	**	0.94	-
Stem internode	P	0.1433 - 0.00053472 * (DAP)	ns	0.02	-119.5
Petiole (+branches)	N	1.5774 - 0.01207070 * (DAP)	*	0.23	-
Petiole (+branches)	P	0.2107 - 0.00367895 * (DAP)	**	0.59	3.3
Leaf blades	N	3.9347 - 0.01114628 * (DAP)	ns	0.14	-
Leaf blades	P	0.2940 - 0.00215054 * (DAP)	*	0.25	-5.2
Pods	N	3.8843 - 0.01475381 * (DAP)	ns	0.13	-
Pods	P	0.4326 - 0.00404694 * (DAP)	*	0.42	-3.6

CONCLUSIONS

The data presented here provide a comprehensive description of N and P distribution within the aerial portion of determinate soybean. The results summarize over 6,500 individual plant analyses and provide a nodally-segmented benchmark for comparative analysis of determinate soybean plant tissue. Variance of P concentration was routinely two to three times higher than for N for all plant parts. Concentrations of N and P generally decreased with time for stem internode, petioles (+branches), and leaf blades, but increased with time for pods. Except for N concentration in stem internodes, which increases with internode number, the N and P concentrations remain nearly constant throughout the growing season. Linear regression was used to quantify temporal relationships between N and P concentrations in each plant part (Table 10). The elemental ratio was calculated by dividing the slope of the N concentration line by the slope of the P concentration line. The resulting ratios were dependent upon plant part with the highest ratios in pods and lowest in the petioles (+branches). The ratios of N to P in internodes and leaf blades were similar. The ratios across nodal position also varied with plant part. Due to their linearity N/P ratios were essentially identical for all sampling dates. These elemental concentration trends and the patterns of variances affecting them from both nodal and temporal sources, are worthy of note for the better interpretation of soybean nutrient analysis, for choice of sampling strategies, and for developing nodally segmented model descriptions of determinate soybean growth and nutrient uptake. Together with similar data reported previously for K, Ca, Mg, Fe, Zn, and Mn this information provides an insight to patterns of nutrient uptake, interaction and redistribution within the determinate soybean canopy during a growing season.

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