STUDIES ON THE INFLUENCE OF FRUIT DEVELOPMENT ON SEASONAL ELEMENTAL CONCENTRATIONS AND DISTRIBUTION IN FRUIT AND LEAVES OF PECAN AND THE INFLUENCE OF FOLIAR K APPLICATIONS ON PECAN SEEDLINGS

By

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PREFACE

This study was conducted to determine the seasonal influence of fruiting on elemental concentrations in pecan leaves, major periods of mineral movement into the fruit, and distribution of elements within the maturing fruit. Particular reference was made to the K nutrition of pecan and and alternative method of supplying K by way of foliar applications.

Chapter II, The Influence of Fruit devleopment on Seasonal Elemental Concentrations and Distribution in Fruit and Leaves of Pecan, was submitted for publication in Communications in Soil Science and Plant Analysis. Chapter III, Influence of Foliar Applications of K_2SO_4 and KNO_3, plus Urea and NH_4NO_3 Spray Adjuvants, and Surfactants on K Concentration of Pecan Seedlings, was revised and submitted for publication in HortScience.

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CHAPTER 1

INTRODUCTION

Pecan's (Carya illinoinensis [Wang] K. Koch) flowering and fruiting processes, including return bloom, nut yield, and quality, are influenced by the nutritional status of the tree. Plant analysis and leaf analysis are methods for determining elemental concentrations in pecan plant tissue. Factors influencing elemental concentration may be either physiological or cultural.

Changes in leaf elemental concentrations occur as the season progresses. Three characteristic trends for seasonal changes in leaf elemental concentrations are:

a) a rapid decrease in concentration early in the season, probably as a result of growth dilution, followed by a steady rise until senescence.

b) a continual increase in both concentration and absolute content until late in the season.

c) a gradual decrease followed by a fairly constant concentration(15).

Fruiting also influences the leaf elemental content. This is demonstrated by differences in leaf elemental concentrations between leaves on fruiting and vegetative shoots. Pecan fruit development has been divided into two periods: (1) the pre-filling period of growth in size, beginning at blossoming and ending with shell hardening, and (2), the filling period of the fruit which begins at the time of shell hardening and ends with separation of the nut from the shuck(6).

The pre-filling period is characterized primarily by formation of the shuck and shell. The kernel filling period corresponds with fruit maturation and with increases in oils, minerals, proteins, and polysaccharides. Therefore, distinct physiological changes are associated with pecan fruit development. Cultural practices such as supplemental foliar fertilization directed at specific fruiting stages and/or leaf condition may influence leaf elemental concentrations, nut size, nut quality, and yield.

A study of the seasonal influence of fruiting on leaf elemental concentrations correlated with seasonal elemental movement into the fruit and location of elemental accumulation within the fruit thus seemed appropriate.

Potassium is an important element in pecan tree nutrition. In a survey of grower's leaf samples from Oklahoma pecan orchards over a three year period, 70% of the samples were found low in K(49). Mature pecan trees respond slowly to soil applied K fertilizers, even when leaf K concentration is below normal (1.0-1.75% K). Potassium applied at 186 kg K/ha for three consecutive years did not affect leaf K concentration in 25 year-old 'Western' pecan trees (50). Potassium application increased NH_4Ac extractable K to the 24 cm depth, indicating available K moved through the root zone but was not absorbed and translocated to the leaves (50). Therefore, several years may lapse between heavy application of K fertilizers and an increase in leaf K concentration.

Potassium shortages may temporarily occur during critical growth periods including rapid accumulation in the leaves 2 to 3 weeks following bud break (54) and during the kernel filling-shuck maturation stage (8). In the latter case, K is translocating from the leaves to the developing fruit faster than roots can absorb K from the soil. A net loss of leaf K may result in potassium leaf scorch, and when severe, premature defoliation (38). In turn, nutrient depletion affects return bloom and fruit retention the following season and contributes to the problem of alternate bearing (47).

An alternative method of supplying K is direct foliar application. Plant response to foliar nutrient spray is much faster than equivalent soil directed applications.

The objectives of this research were to:

1. Determine the seasonal influence of fruiting on leaf elemental concentrations.
2. Determine major periods of mineral movement into the fruit.
3. Identify the location of mineral accumulation within the fruit.
4. Determine the feasibility of supplementing the K requirement of pecan using foliar K applications.

CHAPTER II

INFLUENCE OF FRUIT DEVELOPMENT ON SEASONAL ELEMENTAL CONCENTRATIONS AND DISTRIBUTION IN FRUIT AND LEAVES OF PECAN

KEY WORDS: *Carya illinoinensis*, plant analysis, leaf analysis

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ABSTRACT

The elemental concentrations of leaves and fruits were monitored during one season on fruiting and vegetative pecan shoots. Pecan fruit and leaves of fruiting and vegetative shoots on 31-year-old 'Western' pecan trees were collected biweekly from May 15 through October 15, 1982 and analyzed for N,P,K,Ca,Mg,Fe,Zn and Mn. The concentrations of Ca,Mg,Zn,Fe and Mn were greater in leaves of fruiting shoots. The N concentration was higher in leaves of fruiting shoots the first ten weeks, then was significantly less in leaves on fruiting shoots the latter part of the season. K concentration was lower in leaves of fruiting shoots than vegetative shoots from June 25 through Oct. 15. Leaf P concentration did not appear to be influenced by fruiting. Content of N,K,P, and Zn in the fruit increased slowly until the tenth week after full bloom, then rapidly until fruit maturity. Ca, Mg and Mn accumulation in the fruit was linear throughout fruit development. Fe increased rapidly during early kernel development, then decreased as the fruit matured. Dry weight and volume of the fruit also increased slowly until the tenth week, followed by a rapid increase until maturity. The kernel contained more N, P, Zn and Fe at maturity than the shuck or shell. K, MN, Ca and Mg were highest in the shuck.

INTRODUCTION

Seasonal trends in the elemental composition of pecan leaves have been reported (3,5,9,26) but data describing the influence of fruiting on these trends are incomplete. The seasonal trends in leaf elemental concentration have been discussed with respect to alternate bearing (9), fertilization (5,26) and fruit maturation (10) in pecan. Seasonal changes for leaf elements in various tree species demonstrated similar trends regardless of cultivar (23,25,26), fertilizer level (5,7,16,26), alternate bearing (9), and calendar year (8,17,26).

Fruiting influences the leaf elemental concentrations of pecan (6,10,22). Sparks (22) reported that the concentrations of N,P,K, Fe, B and Zn were lower at fruit maturity in leaves on shoots supporting fruit than shoots with fruit removed in July. Hunter and Hammar (6) sampled pecan leaves in September from bearing and non-bearing shoots and found N,P,K, and Mg were lower on bearing shoots. Fruiting reduced leaf K concentration in apple (1), tung (15), peach (11,12,13), and prune (12), as well as pecan (6).

Elemental distribution within mature pecan fruit and fruit parts has been reported (4,10,21,22). Elemental accumulation in the fruit parts is influenced by the stage of fruit development (4) as well as elemental reserves in the associated shoots (10). Lewis and Hunter (10) divided fruit development into 3 periods. The first was characterized by rapid fruit growth with differentiation of the shuck, shell, and kernel and hardening of the shell. During this period the percent N, Ca, Mg, K and P decreased, but the actual amount of these elements per fruit increased. In the second period of development there was little increase in fruit size, the shell matured, and the kernel was gelatinous. The percent N and P increased significantly during this period, K remained constant, and Ca and Mg decreased. The total amount per fruit of all these elements, except Ca, increased. The third stage represented fruit maturation, and trends in elemental composition were similar to period 2 development.

In this study we examined the effect that fruiting had on leaf elemental concentration throughout the growing season as well as elemental changes in the fruit and the component fruit parts. The purpose of this study was to determine if fruit development influenced elemental distribution within the tree, and when the greatest movement of each element to the developing fruit occurred.

MATERIALS AND METHODS

Trees selected for the study were 31-year-old 'Western' pecans (*Carya illinoinensis* (Wangenh.) C. Koch) bearing a commercial crop. Trees had received 112 kg N ha^{-1} for 5 years, and were growing on a Port silt loam, at the Pecan Research Station in central Oklahoma.

Leaves (the middle pair of leaflets from each of 50 to 60 middle leaves/collection) and fruit (10 fruit/collection) from each of 5 trees were sampled biweekly from May 28 to October 15, 1982. All leaves and fruit were sampled at a height between 3 and 9 m.

Fruit volume was determined using liquid displacement. Fruit and leaves were washed for 1 min. in a liquinox solution, .1 N HCl, then 2 deionized water rinses (20). Shell hardening was detected August 28 (136 days from bud break, DBB), six weeks before fruit maturity on October 15 (184 DBB) (Table 1). On September 15 (154 DBB), the fruit was sufficiently mature to separate into the shuck (involucre), shell (ovary wall) and kernel (cotyledons and embryo) for analysis. The fruit was left intact on all previous sampling dates. Samples were oven-dried at 75°C to a constant weight. Fruit dry weight was recorded, then samples were ground in an electric grinder with stainless steel blades. Leaf samples were ground to pass a 20-mesh screen in a Wiley mill. All samples were stored in air-tight glass jars until analyzed. Prior to analysis, samples were redried at 80°C for 24 hours. N was determined by the macro-Kjeldahl method, P colorimetrically, and K,Ca,Mg, Zn,Fe, and Mn on a Perkin-Elmer 303 atomic absorption spectrophotometer (19).

RESULTS AND DISCUSSION

Fruit Development

Fruit volume and dry weight increased slowly until nine weeks before shuck split (Aug. 3, 111 DBB), then increased rapidly (Fig.1). The increase in fruit volume exceeded the increase in dry weight from August 3 to August 28 (111 to 136 DBB), then paralleled dry weight increase until September 15 (154 DBB). Fruit dry weight increased more rapidly than volume from September 15 to October 15 (154 to 184 DBB). Shell hardening had begun by the Aug. 28 (136 DBB) collection date (Table 1), and at this stage the shell was structurally complete (18,23,24,25). The beginning of shell hardening coincides with the beginning of rapid embryo growth and kernel filling (14). Finch and Van Horn (3) reported that during the early stages of filling the pressure of the expanding seed coat may cause an increase in the volume of the shell. There was no change in dry weight of the shell the last 4 weeks prior to shuck split (Fig.1) and the shell was completely hard by Sept. 15 (154 DBB) (Table 1). On Aug. 28 (136 DBB) the kernel was still in the liquid endosperm stage. Some increases in the fruit volume may be due to the kernel and shell at this stage, although increases in fruit volume the final 4 weeks were probably due to an expansion of the shuck. Fruit increased 44% in volume and 58% in dry weight, during the final 6 weeks prior to shuck split (Aug. 28 to Oct. 15, 136 to 184 DBB). During the final 4 weeks (Sept. 15 to Oct. 15, 154 to 184 DBB) there was no significant change in the dry weight of the shell, a 7% increase in the shuck and a 60% increase in the kernel. The increase in kernel dry weight corresponds with deposition of cotyledonary storage materials such as proteins, oils, minerals and polysaccharides (4). Seventy percent of the kernel dry weight is oil, which is synthesized the last 4-6 weeks of fruit development (23). Although the kernel comprised only 26% of the fruit dry weight on Sept. 15 (154 DBB), by shuck split (Oct. 15, 184 DBB) it comprised 46% of total dry weight of the fruit.

TABLE 1

Growth Stages of Pecan Fruit - 1982

Date	Ave. dry wt. per fruit (g)	Ave. vol. per fruit (ml)	Stage of Development
April 14			Budbreak
May 7 to 13			Pollination
May 28	.03	.100	Fruit enlargement
June 9	.062	.130	Fruit enlargement
June 25	.174	.29	Fruit enlargement
July 7	.422	1.56	Beginning of rapid expansion of kernel
July 21	.914	2.97	Beginning of liquid endosperm stage
Aug. 3	1.81	6.98	Liquid endosperm
Aug. 18	3.02	12.94	Liquid endosperm
Aug. 28	4.06	15.70	Beginning of shell hardening; liquid endosperm stage continues
Sept. 15	6.70	23.34	Gel stage over; shell hard; kernel development
Sept. 29	8.43	29.50	Kernel development; shell coloring slightly
Oct. 15	9.56	28.0	Initial shuck split; fruit maturity

Fruit Elemental Content and Trends

Total N per fruit increased slowly until Aug. 28 (136 DBB), then rapidly until maturity (Fig. 2). N content of the fruit increased 63%, during the final 48 days (Aug. 28 to Oct. 15, 136 to 184 DBB) of fruit development. This increase was due to an increase in the N content of the kernel (Table 2). The distribution of N in the fruit at maturity was 71%, 7%, and 22% in the kernel, shell and shuck, respectively. Earlier reports indicated that the distribution of N in the fruit was 51%, 13%, and 36% (21) and 63%, 11% and 26% (4) in the kernel, shell and shuck, respectively. Kernel dry weight increased 60% and N increased 57%, during the final fruit development (Sept. 15 to Oct. 15, 154 to 184 DBB).

The increase in K content per fruit (Fig. 3) was similar to N (Fig. 2), increasing by 65% during the final 48 days of fruit development, although 44% more K than N was accumulated per fruit. The majority of the K in the fruit was in the shuck (86%) (Table 2). K content of the shuck increased 46% the final 30 days of fruit development, but K content of the shell and kernel remained constant. K movement into the shuck at maturity may cause water movement into the shuck, hydrating it to the point that dehiscense occurs (23).

The accumulation of both Mg and P in the fruit followed similar patterns. Content of both increased gradually until kernel deposition in late Aug., then accumulation was more rapid until maturity (Fig. 4). The greatest increase in fruit P content during maturation occurred in the kernel (Table 2.). During kernel deposition the Mg content of the kernel and shuck increased. Fruit Ca content increased more rapidly than Mg and P, and was not associated with kernel deposition. Fruit Ca content increased linearly until Sept. 15 then remained at the same level between Sept. 15 and Oct. 15 (154 and 184 DBB). The shell and shuck of the fruit each contained approximately the same amount of Ca and were significantly higher than Ca in the kernel (Table 2). Zn content of the fruit increased most rapidly during kernel filling (Fig. 5) with the greatest increase occurring in the kernel (Table 2). The Fe content of the fruit increased rapidly from Aug. 28 to

Sept. 15, then decreased from Sept. 15 through Oct. 15 (154 through 184 DBB) (Fig. 5). During this period the Fe content of the kernel increased, but the Fe content of the shuck decreased 84%, and was probably associated with the loss of chlorophyll as the shuck approached senescence (Table 2). Fruit Mn content increased linearly from May 28 through Sept. 29 (44 through 168 DBB), then decreased between Sept. 29 and Oct. 15 (168 and 184 DBB) (Fig. 6).

At maturity (Oct. 15, 184 DBB), the quantity of each element in the fruit, in descending order was K>N>Ca>P>Mg>Mn>Zn>Fe, which agrees with data by Sparks (21). However, on Sept. 15 and Sept. 29 (154 and 168 DBB) elements were ranked as K>N>Ca>Mg>P>Mn>Fe>Zn. In the filling process both P and Zn increased significantly in the kernel, while Fe decreased in the shuck. Within the fruit the order of magnitude at maturation was N>K>P>Mg>Ca>Mn>Zn>Fe, Ca>N>K>P=Mg>Mn>Fe≥Zn, K>N>Ca>Mg>P>Mn>Zn>Fe in the kernel, shell and shuck, respectively.

Leaf Elemental Concentration and Trends

Leaf N concentration was greatest June 9 (56 DBB), then decreased gradually until fruit maturity, Oct. 15 (184 DBB) (Fig. 2). A similar trend in leaf N concentration was reported for trees in their "on" and "off" production years (9). N concentration was greater in leaves on fruiting than vegetative shoots sampled May 28, June 9, 25, July 21 and Aug. 3 (44,56,72,98 and 111 DBB), and less on Aug. 28, Sept. 29 and Oct. 15 (136,168 and 184 DBB). Krezdorn (9) reported that leaf N concentration of "on" trees was less during Aug. and Sept. than "off" trees although leaf N was equal from April through July.

The leaf K concentration was highest in both fruiting and vegetative shoots May 28 (44 DBB), decreasing until June 25 (72 DBB)

(Fig. 3), then increased significantly to July 7 (84 DBB), followed by a gradual decrease the remainder of the season. K concentration was higher in leaves of vegetative shoots than fruiting shoots on all sampling dates except May 28, June 9, July 21 and Oct. 15 (44,56,98 and 184 DBB).

TABLE 2

Seasonal Changes in the Elemental Content of the Shuck, Shell and Kernel

	Date					
Fruit Part	9/15	9/29	10/15	9/15	9/29	10/15
	N (mg/fruit)			P (mg/fruit)		
Kernel	25.3a2	43.9b3	59.0c3	3.9a3	5.6b3	13.4c3
Shell	5.3a1	6.2a1	5.7a1	0.7a1	0.6a1	0.8a1
Shuck	22.9a2	23.3a2	18.7a2	2.1a1	2.2a1	2.9a2
	K (mg/fruit)			Ca (mg/fruit)		
Kernel	15.8a2	14.4a2	18.4a2	2.3a1	2.9a1	2.0a1
Shell	3.7a1	3.7a1	2.7a1	9.3a2	10.7a2	10.3a2
Shuck	69.8a3	91.3b3	125.9c3	10.5a2	12.1a2	10.8a2
	Mg (mg/fruit)			Zn (µg/fruit)		
Kernel	3.1a2	3.8ab2	4.9b2	76a2	108b2	147c3
Shell	1.4a1	1.2a1	0.8a1	12a1	11b1	11a1
Shuck	6.4a3	7.8b3	8.0bc3	127a3	124a2	116a2
	Fe (µg/fruit)			Mn (µg/fruit)		
Kernel	80a1	72a1	100a1,2	221a1	330a2	364a2
Shell	43a1	36a1	13a1	128a1	143a1	106a1
Shuck	360a2	296b2	61c1	462a2	608a3	476a2

[z]Mean separation within rows using letters, and columns using numbers by Duncan's Multiple Range Test, 5% level.

Leaf P concentration decreased significantly from May 28 to June 9 (44 to 56 DBB), then remained constant through Oct. 15 (184 DBB) (Fig. 4). Fruiting did not affect the leaf P concentration (Table 2).

There was no interaction between sampling date and fruiting status associated with leaf Ca, Mg, P, Zn, Fe and Mn concentration. Therefore, means of main effects for fruiting status and sampling date are presented. Leaf Ca, Mg, Zn, Fe and Mn concentrations were greater in fruiting than vegetative shoots (Table 3). The leaf Mg concentration increased from May 28 to June 9 (44 to 56 DBB), then remained stable the remainder of the season (Fig. 4). Leaf Ca concentration increased gradually from May 28 to Sept. 15 (44 to 154 DBB) then remained constant through Oct. 15 (184 DBB). Leaf Zn and Fe concentrations both fluctuated widely during the growing season (Fig. 5). Zn concentration increased from a minimum concentration on May 28 (44 DBB) to the maximum on July 7 (84 DBB), decreased to Aug. 18 (126 DBB), then increased to Sept. 15 (154 DBB), remaining stable through Oct. 15 (184 DBB). The lowest Fe concentration in the leaves was on May 28 (44 DBB), then increased to the maximum concentration Aug. 3 (111 DBB). The leaf Fe concentration decreased to 62 ppm by Aug. 18 (126 DBB), and did not change significantly through Oct. 15 (184 DBB). Leaf Mn concentration increased linearly throughout the growing season (Fig. 6).

These data suggest that fruiting influences the distribution of most elements within pecan shoots. Leaf Ca,Mg,Zn,Fe and Mn concentrations were higher in leaves of fruiting shoots than in the leaves of vegetative shoots. This is an indication that these elements are preferentially transported to shoots supporting fruit.

It appears that the fruit is capable of diverting transport of elements to fruiting shoots even during early fruit growth and development. Leaf N was greater in fruiting than vegetative shoots the first part of the season, then lower the latter part of the season. In late August kernel deposition had begun and N was depleted more rapidly in leaves on fruiting than vegetative shoots.

TABLE 3

The Effect of Fruit Development on Leaf Elemental Concentration

Element	Fruiting Shoots	Vegetative Shoots
	% Dry Weight	
P	0.150A[z]	0.155A
Ca	1.05B	0.94A
Mg	0.51B	0.47A
	µg/gm Dry Weight	
Zn	106B	96A
Fe	73B	66A
Mn	489B	448A

[z] Mean separation within rows by Duncan's Multiple Range Test, 5% level. There were no significant interactions between sampling date and fruiting. All sampling dates are pooled.

A significantly lower concentration of K was found in the leaves of fruiting shoots early in the season (June 25), even though the fruit was still small at this time (.1 ml volume). This suggests that the transport of K was being directed to the fruiting shoots, specifically to the fruit at the expense of the leaves. Sparks (22) had reported that leaves from shoots with the fruit removed on July 15 had a greater K concentration Sept. 22 than shoots with fruit. He also suggested that heavy fruiting induced leaf scorch in pecan due to a net loss of K from the leaves as the fruit nears maturity. These data indicate that not only is there a net loss of K from the leaves near fruit maturity, but K concentration in the leaves of fruiting shoots is less during most of the growing season due to a preferential transport of K to the fruit.

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Fig. 1. Development of the pecan fruit and fruit parts. Vertical bars indicate significance for date, and letters for fruit part within date, LSD 5% level.

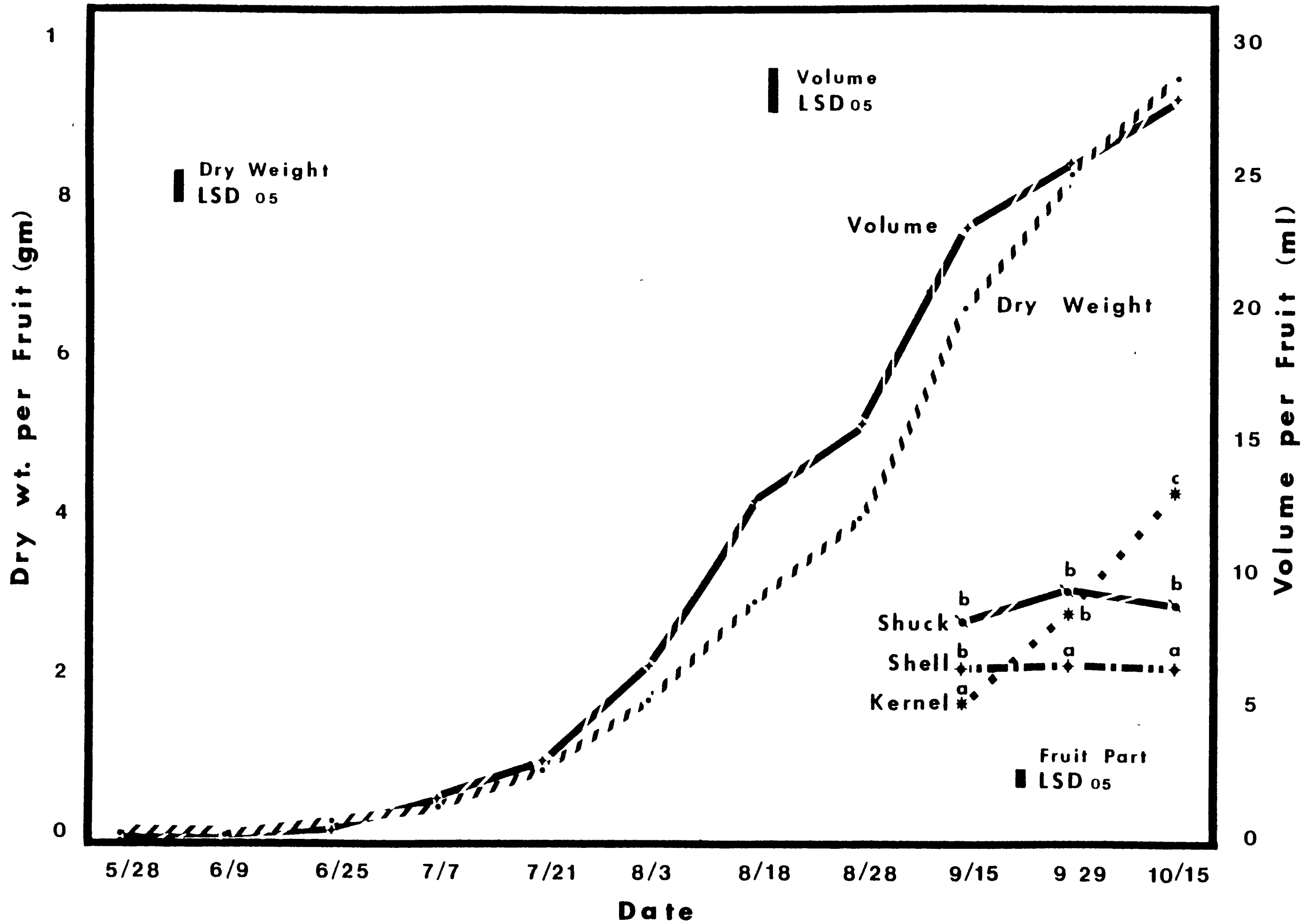
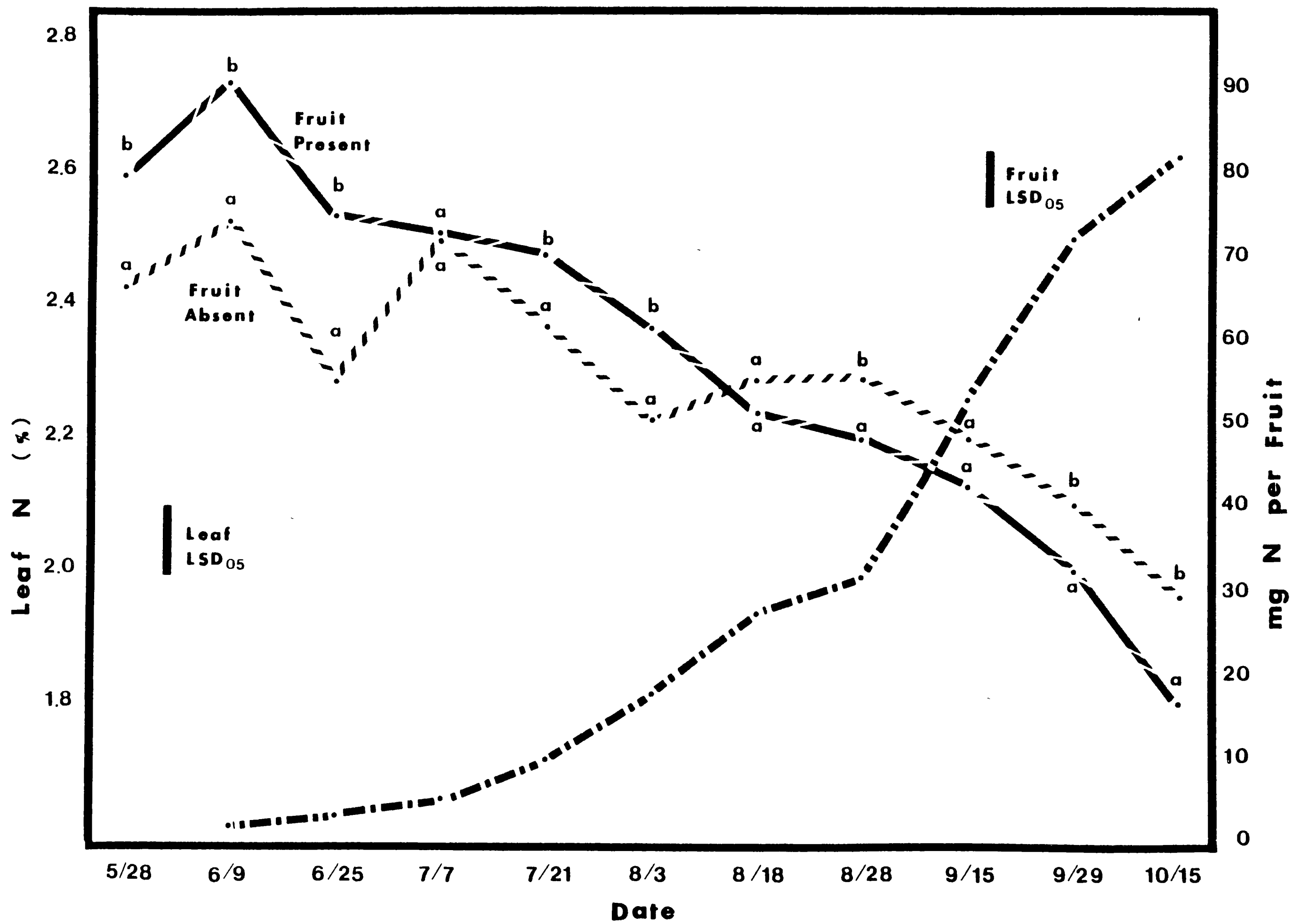
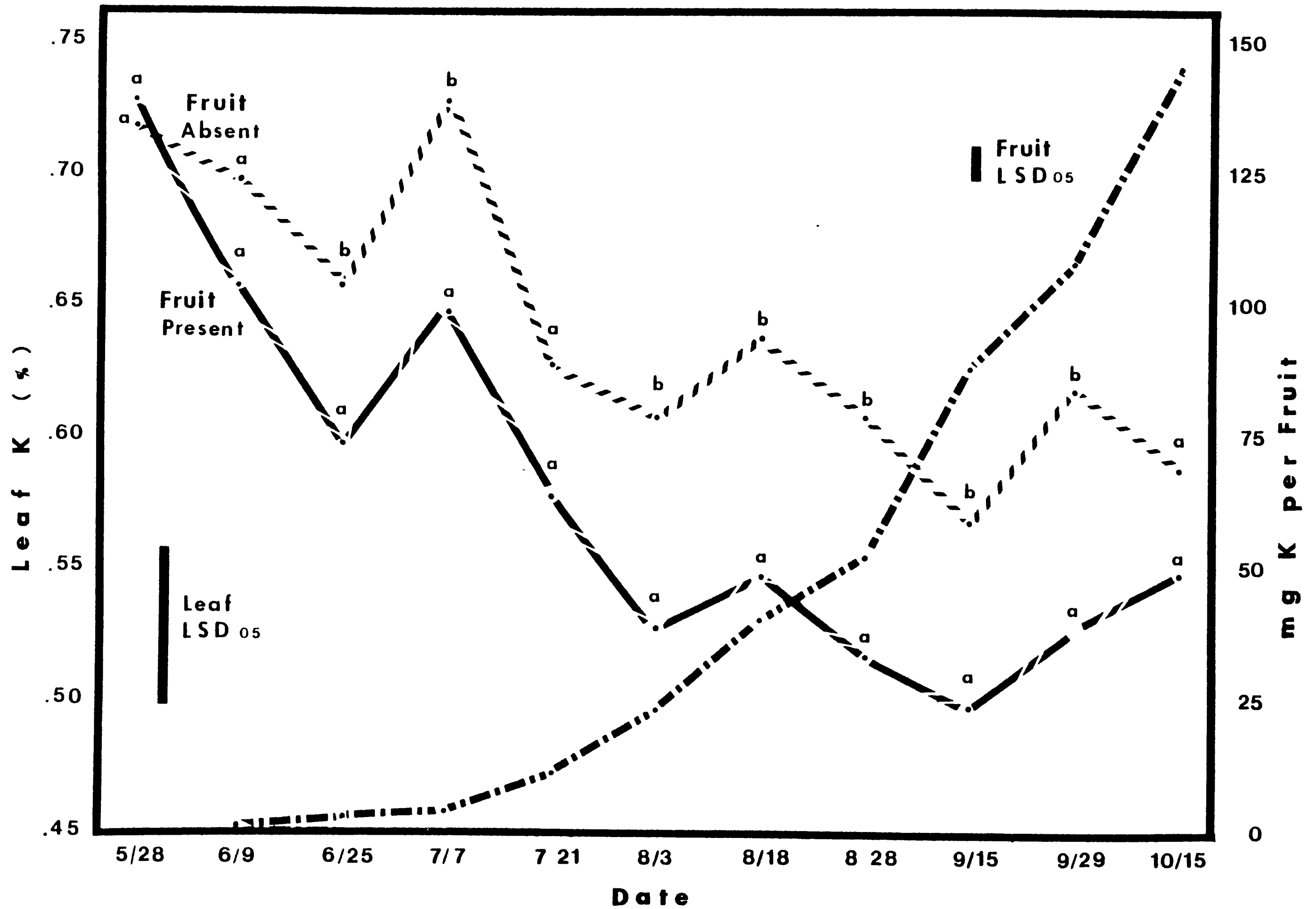

Dry Weight
LSD 05
Volume
LSD 05
Volume
Dry Weight
Shuck
Shell
Kernel
Fruit Part
LSD 05
Dry wt. per Fruit (gm)
Volume per Fruit (ml)
Date
5/28
6/9
6/25
7/7
7/21
8/3
8/18
8/28
9/15
9 29
10/15

Fig. 2. Seasonal trends in leaf N concentration from fruiting and vegetative shoots, and fruit N content. Vertical bars indicate significance for date within shoot-type or fruit, letters indicate significance for shoot-type within date, LSD 5% level.



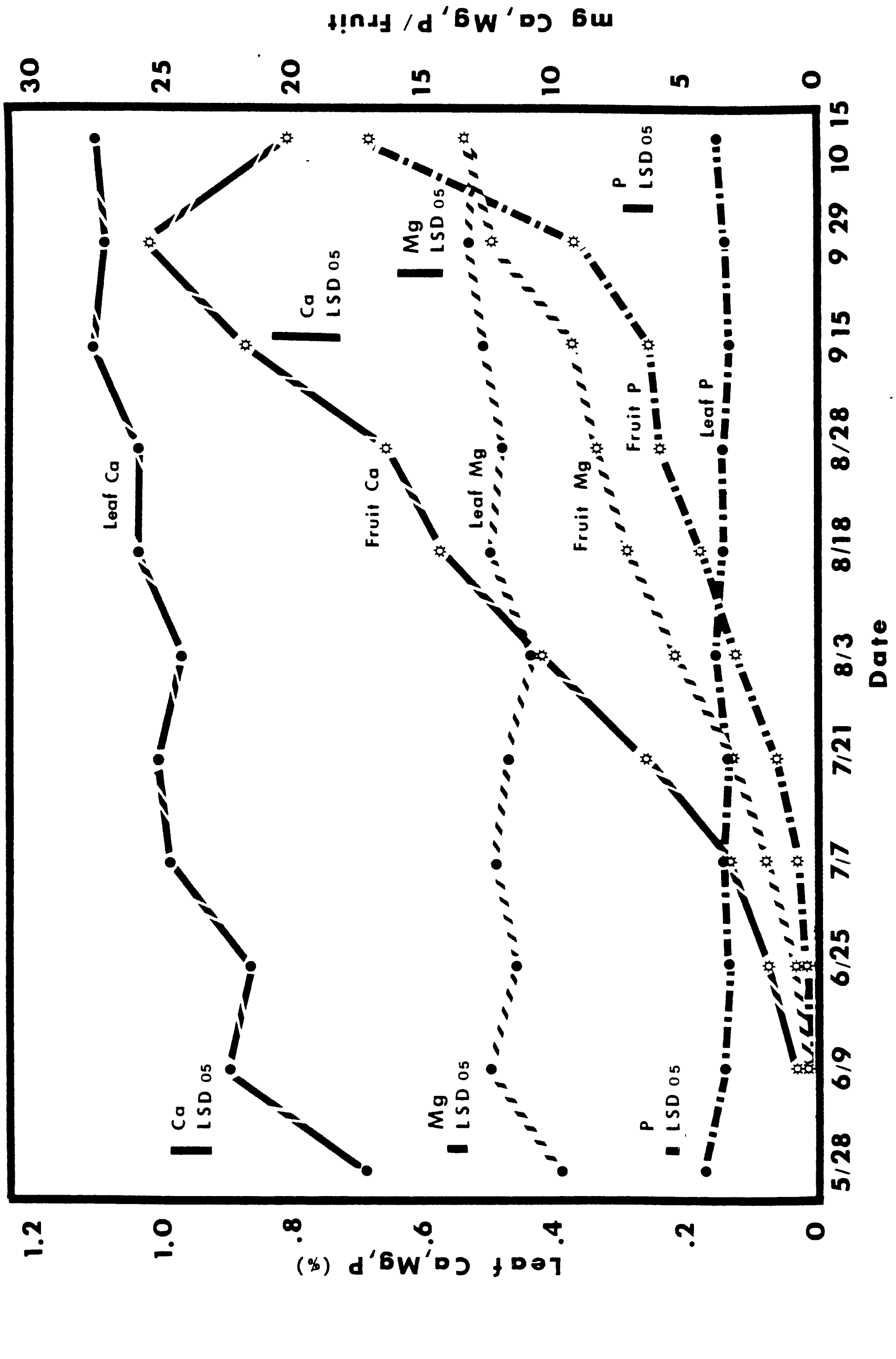
2.8
2.6
2.4
2.2
2.0
1.8
Leaf N (%)
90
80
70
60
50
40
30
20
10
0
mg N per Fruit
Fruit Present
Fruit Absent
Fruit LSD05
Leaf LSD05
5/28
6/9
6/25
7/7
7/21
8/3
8/18
8/28
9/15
9/29
10/15
Date

Fig. 3. Seasonal trends in leaf K concentration from fruiting and vegetative shoots, and fruit K content. Vertical bars indicate significance for date within shoot-type or fruit, letter indicates significance for shoot-type within date, LSD 5% level.



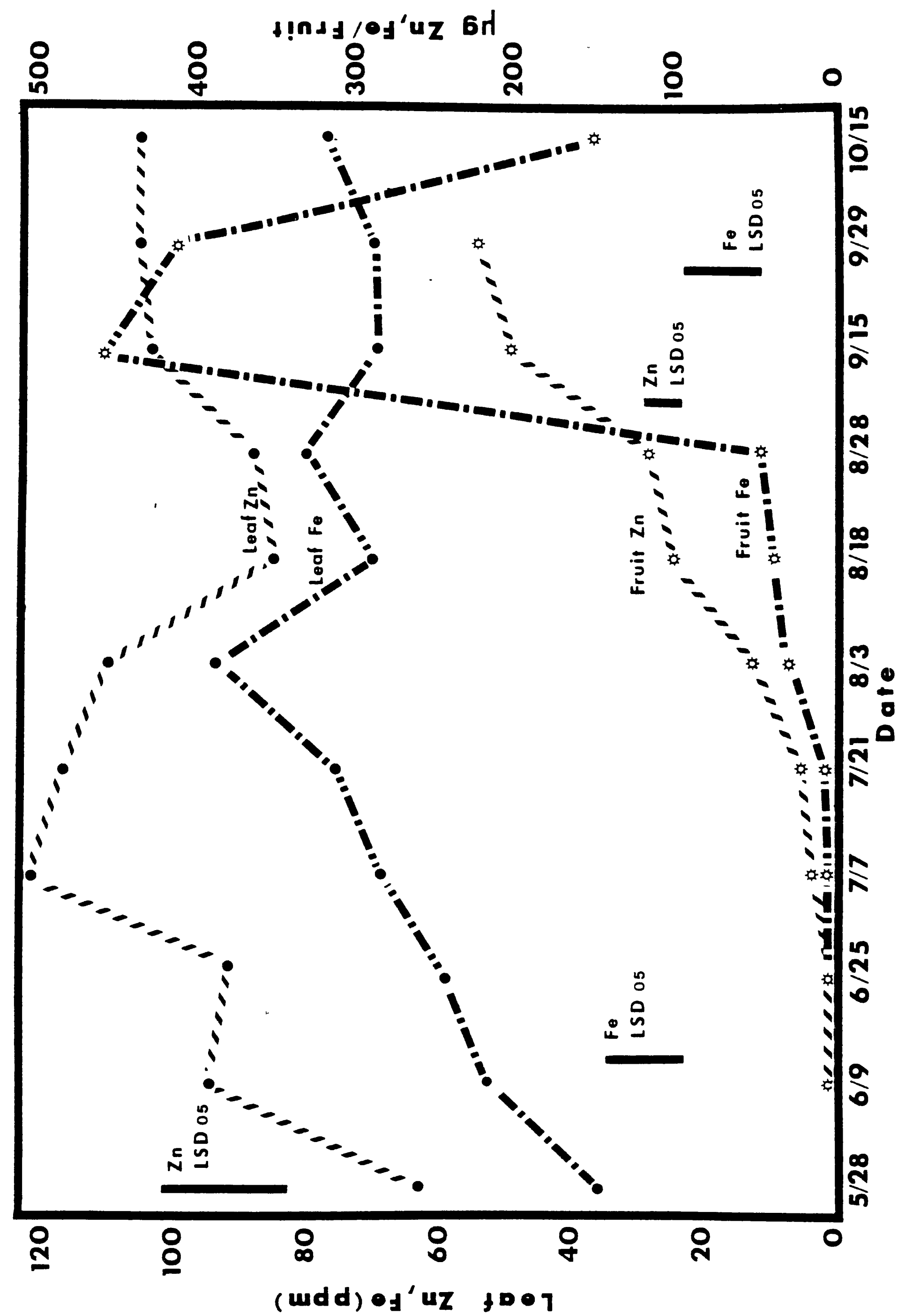
.75
.70
.65
.60
.55
.50
.45
Leaf K (%)
150
125
100
75
50
25
0
mg K per Fruit
Fruit Absent
Fruit Present
Fruit LSD 05
Leaf LSD 05
a
b
5/28
6/9
6/25
7/7
7 21
8/3
8/18
8 28
9/15
9/29
10/15
Date

Fig. 4. Seasonal trends in leaf Ca, Mg and P concentration and fruit Ca, Mg and P content. Fruiting and vegetative shoot-types are pooled. Vertical bars indicate significance for date, LSD 5% level.



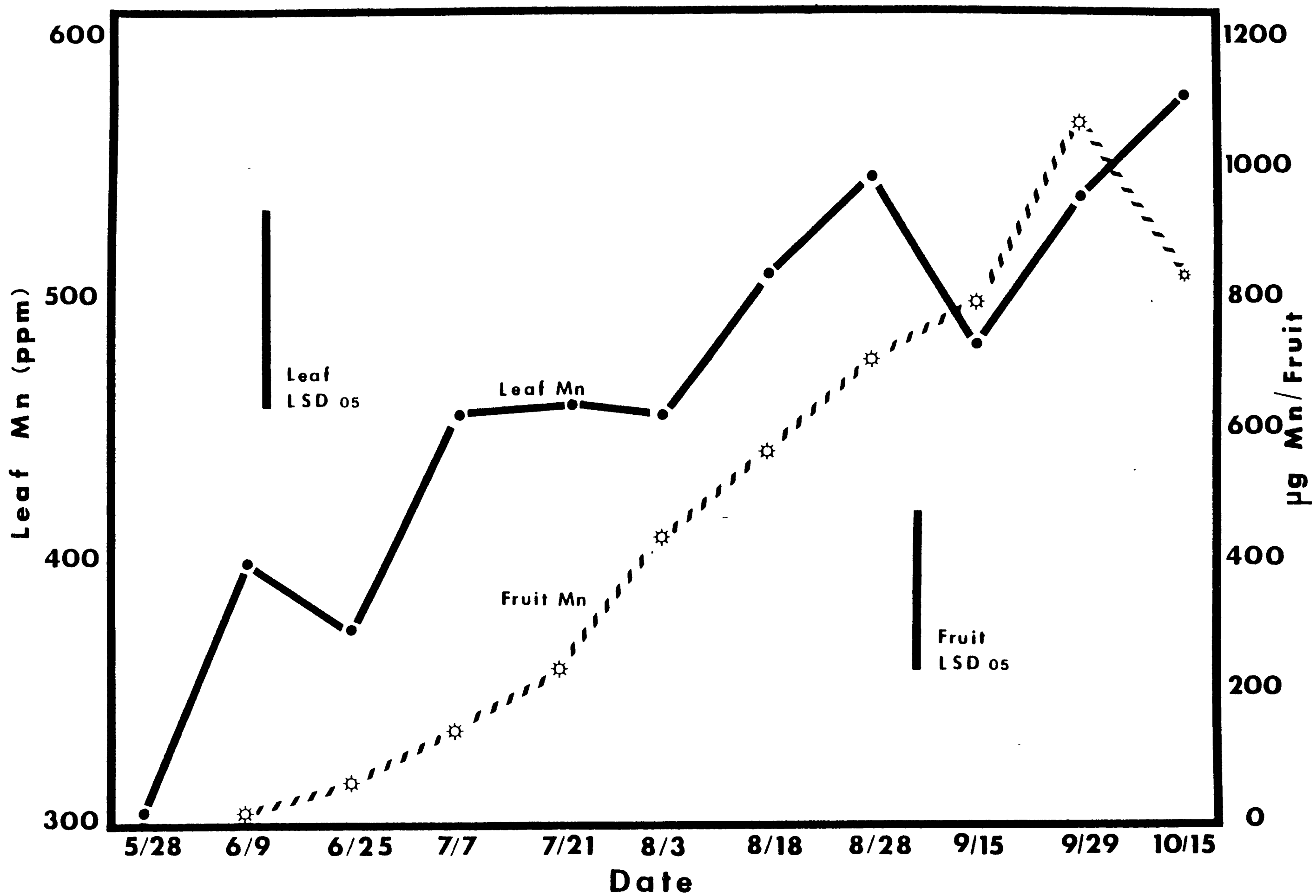
mg Ca, Mg, P/ Fruit
30
25
20
15
10
5
0
Leaf Ca,Mg,P (%)
1.2
1.0
.8
.6
.4
.2
0
Date
5/28
6/9
6/25
7/7
7/21
8/3
8/18
8/28
9 15
9 29
10 15
Leaf Ca
Fruit Ca
Leaf Mg
Fruit Mg
Fruit P
Leaf P
Ca LSD 05
Mg LSD 05
P LSD 05

Fig. 5. Seasonal trends in leaf Zn and Fe concentration, and fruit Zn and Fe content. Fruiting and vegetative shoot-types are pooled. Vertical bars indicate significance for date, LSD 5% level.



Leaf Zn,Fe(ppm)
µg Zn,Fe/Fruit
Date
5/28
6/9
6/25
7/7
7/21
8/3
8/18
8/28
9/15
9/29
10/15
0
20
40
60
80
100
120
0
100
200
300
400
500
Leaf Zn
Leaf Fe
Fruit Zn
Fruit Fe
Zn LSD 05
Fe LSD 05
Zn LSD 05
Fe LSD 05

Fig. 6. Seasonal trends in leaf Mn concentration, and fruit Mn content. Fruiting and vegetative shoot-types are pooled. Vertical bars indicate significance for date, LSD 5% level.



600
500
400
300
Leaf Mn (ppm)
1200
1000
800
600
400
200
0
µg Mn/Fruit
Leaf
LSD 05
Leaf Mn
Fruit Mn
Fruit
LSD 05
5/28
6/9
6/25
7/7
7/21
8/3
8/18
8/28
9/15
9/29
10/15
Date

CHAPTER III

INFLUENCE OF FOLIAR APPLICATIONS OF K_2SO_4 AND KNO_3, PLUS UREA AND NH_4NO_3 SPRAY ADJUVANTS, AND SURFACTANTS ON K CONCENTRATION OF PECAN SEEDLINGS

Key Words: Carya illinoinensis, foliar K sprays, plant analysis, leaf analysis

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Abstract

Greenhouse experiments using seedling pecan trees tested rates of K_2SO_4, surfactants, repeat applications of K_2SO_4, K sources, and nitrogen adjuvants. Leaf and stem K concentrations increased linearly with rates of 0 to 87.1 g/l K_2SO_4 applied 5 times at 14 day intervals. Phytotoxicity was negligible to 10.9 g/l K_2SO_4. Surfactants did not affect leaf K concentrations. KNO_3 and K_2SO_4 individually applied 2 times at 14 day intervals increased leaf K concentration 0.45% and 0.26% over the control, respectively. KNO_3 or K_2SO_4 at 25.3 and 21.8 g/l, in combinations with urea and/or NH_4NO_3 at 6.25, 12.50 and 25.00 g/l, increased leaf K concentration significantly and the increase

was consistently greater using KNO_3 than K_2SO_4. Both urea and NH_4NO_3 applied with either KNO_3 or K_2SO_4 increased leaf K concentrations. The increase was linear with application rate. Negligible phytotoxicity occurrred when urea or NH_4NO_3 were applied at 6.25 or 12.50 g/l, or when urea + NH_4NO_3 was applied at 6.25 g/l.

Potassium shortages in pecan occur frequently in Oklahoma (26), and elsewhere in the south, reducing yield and nut quality. Hunter and Hammar (11) reported a high positive correlation between the K content of pecan leaves and oil content of the kernel. Likewise, there appears to be a positive relationship between yield and leaf K concentration of pecan (23).

Soil applications of K have not consistently increased leaf K concentration or yield (7,26).

An alternative method of supplying K is direct application to the foliage. Foliar K applications in apple (21), peach (17), mangoe (24), orange (16,20), lemon (14), and grapefruit (5) have variously increased leaf K concentration (5,16,20,21), fruit size (5), yield (5), fruit color (5,21), and fruit quality (14). Foliar K applications in pecan have increased leaf K concentration (8), yield (13), and nut quality (12). Studies with pecan concentrated mainly on the difference between early or late season spray application using KNO_3 or KCl. Additional information concerning foliar K absorption is needed.

Addition of surfactants to foliar sprays enhanced absorption of nutrient elements (1,3,4,9,30). Leaf K content and leaf injury are dependent on the concentration of foliar spray and the frequency of application (2). KNO_3 applied to citrus trees at 96 g/l did not injure the foliage (8), while others reported injury at 24 (20) and 48 g/l (2). Gossard and Nevins (8) sprayed pecan trees with KNO_3 at 2.5, 5.1 and 10.0 g/l in late April with no evidence of foliar injury. Sprays repeated in June with rates of 10.1, 20.2, and 50.0 g/l resulted in trace injury at 10.1 g/l with phytotoxicity increasing with spray concentration. The anion carrier affects cation absorption characteristics in both roots (18), and leaves (30). Spray adjuvants of urea and NH_4NO_3 increased foliar Zn absorption in pecan leaflets by 84 and 151%, respectively, and are commonly used in foliar nutrient sprays (29).

The purpose of this research was to determine the feasibility of supplementing the K requirement of pecan by foliar K applications.

Methods. Foliar potassium applications for each experiment were applied to upper and lower leaf surfaces until run-off using a hand held sprayer. Pot surfaces were fitted with wire-rimmed paper plates to avoid media spray contamination. Leaf and stem samples were washed for 1 minute in a Liquinox solution, 0.1N HCl, then 2 deionized water rinses (28). Root samples were washed in Liquinox, distilled water, then 2 deionized water rinses. All tissue samples were oven-dried at 75°C to a constant weight, then ground in a Wiley mill, leaves to pass a 20-mesh screen ($1mm^2$) and stems and roots a number 4 screen ($4mm^2$). All samples were stored in air-tight glass jars until analyzed. Prior to analysis, samples were redried at 80°C for 24 hours. N was determined by the macro-Kjeldahl method, P colorimetrically, and K, Ca, Mg, Zn, Fe, and Mn on a Perkin-Elmer 303 atomic absorption spectrophotometer (27).

Experiment 1. Seedling pecans from 'Western' nuts were germinated and grown in 19.05 cm azalea pots with perlite and watered with a modified Hoagland's solution minus K (6,10). A randomized complete block design was employed with 10 single plant replications. Seedlings had simple leaves and were approximately 21 cm in height and 8 weeks old. One application of K_2SO_4 at rates of 0, 10.9, 21.8, 43.6, and 87.1 g/l was applied on March 18, 1982, between 3:00 and 6:00 p.m., and 26.7-32.2^{o}C. Triton Ag-98 (alkyarylpolyoxyethylene glycols) at 2.5 ml/l was added as a surfactant. Two days later, leaf discs (1cm^2) were sampled between the midrib and margin, then washed and dried as described. Potassium concentration was then determined.

Experiment 2. Seedlings were grown in perlite as previously described. Seven replications of seedlings with compound leaves emerging were used in a randomized complete block design. Foliar treatments were: (a) no surfactant, no K_2SO_4, (b) no surfactant, K_2SO_4 at 21.8 g/l, (c) four commercially available surfactants with K_2SO_4 at 21.8 g/l. Ortho X-77 (alkylarylpolyoxyethylene glycols, free fatty acids, isopropanol), Millers's Spray Aid (alkylarylpolyoxyethylene glycol phospate ester), Triton CS-7 (alkylarylpolyethoxylate and sodium salt of alkylsulfonatedalkylate) at .625 ml/l, and Triton B-1956 (modified phtalic glycerol alkyd resin) at .156 ml/l. Treatments were applied once on June 7, 1982, between 3:00 and 5:00 p.m., and 26.7-32.2^{o}C. Two days later, total leaves were harvested excluding petioles and rachis, then prepared and analyzed as described earlier.

Experiment 3. On June 18, 1982, pecans from 'Western' nuts were planted and grown in 2 parts peat: 1 perlite with 1.78 kg 0-8.3-0, 5.95 kg dolomite, 111.25 g fritted trace elements (FTE 303), and .89 kg Aqua-Gro (wetting agent) per cubic meter incorporated in the media. A trace element mix (STEM) was applied at 237 mg/19.05 cm pot 6 weeks after planting. Nitrogen was supplied at 0.2 g/l every watering using NH_4NO_3.

Foliar applications of K_2SO_4 were repeated five times at 14 day intervals beginning on August 4, 1982 when first compound leaves had emerged. Treatments included a weekly soil application of 0.5 g/l K and foliar rates of 0, 5.4, 10.9, 21.8, 43.6 and 87.1 g/l K_2SO_4. Miller's Spray-Aid at .625 ml/l was added as a surfactant. Leaves, stems, and roots were harvested on October 27, 1982, and washed by the methods previously described. Dry weight of each plant part was recorded. Elemental concentration and content for each element was determined.

Experiment 4. Seedlings were grown as described in Experiment 3. Two K sources, KNO_3 and K_2SO_4, plus NH_4NO_3 and/or urea, were applied foliarly two times at 14 day intervals beginning November 20, 1982. Both K sources supplied 9.8 g K/l equivalent to 25.3 and 21.8 g/l KNO_3 and K_2SO_4, respectively. Urea or NH_4NO_3 was applied at 6.25, 12.50 and 25.00 g/l. Miller's Spray-Aid was added at .625 ml/l. Leaves, stems, and roots were harvested on December 12, 1982, then washed and analyzed as above.

Results. Experiment 1. Since leaf K content and leaf injury are dependent on concentration of K_2SO_4 in the spray, this experiment was intended to find the highest safe concentration. The leaf K concentration was linearly related to the rate of K_2SO_4 (Table 1). Leaf K concentration at 87.1 g/l had 0.36% more K than the control (0.48% K) after one application. No foliar injury was observed for any K_2SO_4 rate. This was surprising in view of the high rates (0 to 32.7 kg/.38 kl) used. High air temperatures and humidity increase citrus leaves' susceptibility to spray injury (2). Spray injury to pecan leaves was more severe in August (32.2°C) than in June (27.2°C) even though KNO_3 spray rates were the same (8). Changes in leaf physiological condition and/or higher temperatures were factors suggested to influence phytotoxicity (8). In this experiment the temperatures were moderately high (26.7-32.2°C) and humidity high. The 21.8 g/l K_2SO_4 rate (8.26 kg/.38 kl) falls within range of safe concentraions used in recent field research. K_2SO_4 was foliarly applied in May at 0 to 24 g/l to 15 year-old 'Mohawk' pecan trees with no apparent foliar injury (25).

TABLE 1

The Influence of K_2SO_4 Application Rate on Leaf K Concentration

K Rate (g/l)	Leaf K (% Dry Weight)
0^z	0.47
10.9	0.51
21.8	0.65
43.6	0.71
87.1	0.83
Linear	.0001
Quadratic	.0679

^{z}One application

Experiment 2. Surfactants were employed to examine their effectiveness on leaf K absorption. There was no difference in leaf K concentration among the surfactants and surfactant treatments were not significantly different from the K_2SO_4 application alone (Table 2). However, all treatments with K (K_2SO_4 at 21.8 g/l) were significantly greater than the control. K_2SO_4 treatments had 0.13% more K than the control compared to a 0.17% difference associated with the 21.8 g/l treatment in Experiment 1. Both experiments represent a 0.15% average increase in leaf K concentration after one application.

TABLE 2

The Influence of Selected Surfactants on Leaf K Absorption[x]

Surfactant	Leaf K (% Dry Weight)
Control	0.33 a[z]
None[y]	0.45 b
Triton CS-7	0.45 b
Ortho X-77	0.43 b
Miller's Spray-Aid	0.46 b
Triton B-1956	0.44 b

[x]One application
[y]K_2SO_4 at 21.8 g/l
[z]Means followed by the same letter are not significant at the 5% level by Duncan's Multiple Range Test.

The inconsistency of surfactants in inorganic ion penetration has been described (31). In this experiment the very low concentrations of surfactants (.156 to .625 mls/l) were used at the manufacturer's lowest recommended rates. These results do not preclude significant effects by surfactants of different chemical nature and concentration (31). Green and Bukovac (9) determined that the effectiveness of surfactants in decreasing surface tensions was related to their concentration. Spray surface tension, in turn, affects stomatal penetration. Spontaneous spray inflitration of stomata, or mass flow, requires surface tension of 25-30 dyn cm^{-1} (22). Such low surface tension has been acheived by organosilicone and fluorocarbon-based surfactants (19).

Experiment 3. The K concentration in the leaves and stems was linearly related to the foliar K_2SO_4 concentration (Table 3). Whole plant K concentration was also significant. There was no effect on root K concentration, and it appears from trend analysis that foliarly applied K did not readily translocate to the roots. The weekly soil application of 0.5 g/l K was within range of the 21.8 and 43.6 g/l foliar rates however, and suggests significant effects of foliar treatments may be masked. Mobility of foliarly applied inorganic ions has been determined by Kannan and others (15) as K(Rb)>Mo>Mn>Fe>Zn. It appears K was absorbed by the roots and translocated to the leaves as indicated by the soil treatment's leaf K concentration. The soil treatment's leaf K concentration was significantly greater than the control, significantly less than the 43.6 and 87.1 g/l foliar rates, and not significantly different from the lower to medium foliar rates.

TABLE 3

The Influence of K_2SO_4 Application Rate on K Concentration and Content of Pecan Seedlings[z]

K Rate	K (% dry weight)				K (mg/plant part)				Dry Weight (gm)				Phytotoxicity Index[y]
g/l	Leaf	Stem	Root	Whole Plant	Leaf	Stem	Root	Whole Plant	Leaf	Stem	Root	Whole Plant	Leaf
Soil Application													
0.5	0.84	0.37	1.06	0.87	217	30	248	12,634	25	8	24	56	0.5
Foliar Application													
0	0.51**[x]	0.24**	0.65**	0.52**	152	18**	136**	7,704	30	7	21	58	0.4
5.4	0.66	0.29	0.58**	0.60	189	19	153	10,068	29	7	24	55	0.4
10.9	0.76	0.30	0.66**	0.67	225	22	180	11,998	29	7	26	58	0.8
21.8	0.97	0.35	0.81	0.84	292	27	232	15,957	30	7	27	64	1.8
43.6	1.26**	0.42	0.81	0.99	376**	35	210	17,906	30	8	25	63	1.9
87.1	1.36**	0.40	0.65**	1.02*	381**	27	120*	13,703	28	7	17	53	2.2
Linear	**[w]	**	NS	**	**	**	NS	**	NS	NS	NS	NS	
Quadratic	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	*	NS	

[z]Five applications at 14 day intervals
[y]0 = No Phytotoxicity, 4 = Severe Phytotoxicity
[x]Significantly different from weekly 0.5 g/l K, (*)5% level, (**)1% level
[w]Significant at 5% level(*), 1% level(**)

The K content (mg K) of plant parts and whole plant K follows trends of K concentration (%K). A significant quadratic effect of foliar rates was found in root K content, increasing to 21.8 g/l, then decreasing with higher rates. Dry weight of roots followed the same trend and was the only significant difference among plant parts. Leaves treated with 43.6 and 87.1 g/l K_2SO_4 exhibited significant phytotoxicity with severe curling and stunting occurring in some cases. Reduction in assimilation of photosynthate probably accounts for these decreased effects.

Leaf Mg concentration was decreased by soil and foliar K treatments by 18%. Leaf, stem, and whole plant N concentration also seemed to be affected negatively but the results were inconsistent. Neither leaf Ca, P, Zn, Fe, nor Mn concentrations were affected by K treatments (data not shown).

Experiment 4. Foliar treatments of KNO_3 or K_2SO_4 were significantly higher in leaf K concentration than the control (Figure 1). KNO_3 was 0.45% and K_2SO_4 0.26% greater than the control (0.48% K). In addition, leaf K concentration was consistently greater using KNO_3 than K_2SO_4. Addition of urea or NH_4NO_3 increased leaf K concentration, and the increase was linearly related to application rate (Figure 1). NH_4NO_3 significantly increased leaf K concentration at 6.25 g/l and urea + NH_4NO_3 was greater at the 12.50 g/l rate. It is unclear which concentration or combination of NH_4NO_3 or urea resulted in the highest leaf K concentration. Leaf N concentration also increased with increasing concentration of urea and NH_4NO_3 (Figure 2). Urea + NH_4NO_3 in combination with KNO_3 at 6.25 and K_2SO_4 at 12.50 g/l resulted in higher N concentrations than treatments without foliar applied N. Each of urea, NH_4NO_3, and urea + NH_4NO_3 at 25.00 g/l resulted in highly significant increases in leaf N concentration. Severe phytotoxicity was associated with these treatments (Table 5). Leaf Mg concentration was significantly decreased by foliar K applications (data not shown). The decrease was less with addition of urea or NH_4NO_3. Leaf P concentration was increased by KNO_3 plus NH_4NO_3 at 25.00 g/l as well as KNO_3 or K_2SO_4 plus urea + NH_4NO_3 at 25.00 g/l. K_2SO_4 decreased leaf P concentration. Leaf Ca,Fe,Zn, and Mn concentrations were not affected by foliar K treatments (data not shown).

TABLE 4

The Influence of K Source on Stem K Concentration

K Source	Stem K (% Dry Weight)
None	.26a[z]
KNO_3	.30b
K_2SO_4	.29b

[z]Main effects of K source

Means followed by the same letter are not significant by the protected LSD, 5% level.

Stem K concentration increased with foliar applications of KNO_3 or K_2SO_4. However, the increase in stem K concentration was not significantly different using KNO_3 or K_2SO_4 (Table 4). Root K concentration was not affected by either foliar KNO_3 or K_2SO_4 treatments or by the addition of NH_4NO_3 and urea. Apparently, foliarly applied K did not translocate to the roots in significant amounts.

In summary, foliar applications of K increased the leaf and stem K concentrations. Repeated applications of K_2SO_4 increased leaf K concentration greater than single applications as in Experiments 1 and 2. The carbohydrate-based surfactants apparently did not enhance K absorption. Nitrogen spray adjuvants were very effective in increasing leaf and stem K concentrations when applied in combination with KNO_3 or K_2SO_4. The KNO_3 source of K increased leaf K greater than K_2SO_4. Foliar injury occurred at higher spray concentrations. KNO_3 and K_2SO_4 at 25.3 and 21.8 g/l, respectively, and urea or NH_4NO_3 up to 12.50 g/l, and urea + NH_4NO_3 at 6.25 g/l were determined as safe concentrations (Table 5).

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TABLE 5

The Influence of K Source, NH_4NO_3 and Urea, on the Phytotoxicity of Pecan Leaf[x]

N Source	Rate (g/l)	Phytotoxicity Index[y]	
		KNO_3	K_2SO_4
No Nitrogen[z]	0	0.0	0.4
NH_4NO_3	6.25	0.6	0.0
NH_4NO_3	12.50	2.5	1.8
NH_4NO_3	25.00	4.7	4.3
Urea	6.25	0.3	0.2
Urea	12.50	1.9	0.9
Urea	25.00	3.8	1.9
Urea + NH_4NO_3	6.25	1.7	1.0
Urea + NH_4NO_3	12.50	4.0	2.9
Urea + NH_4NO_3	25.00	4.8	4.9

[x] Seedling pecans, two applications at 14 day intervals.
[y] 0 = No Phytotoxicity, 5 = Severe Phytotoxicity; average of two readings.
[z] KNO_3 25.3 g/l; K_2SO_4 21.8 g/l.

Fig. 1. The influence of K source, NH_4NO_3 and urea on leaf K concentration. Both K sources supplied 9.8g k/l. Vertical bars indicate the standard error of the mean.

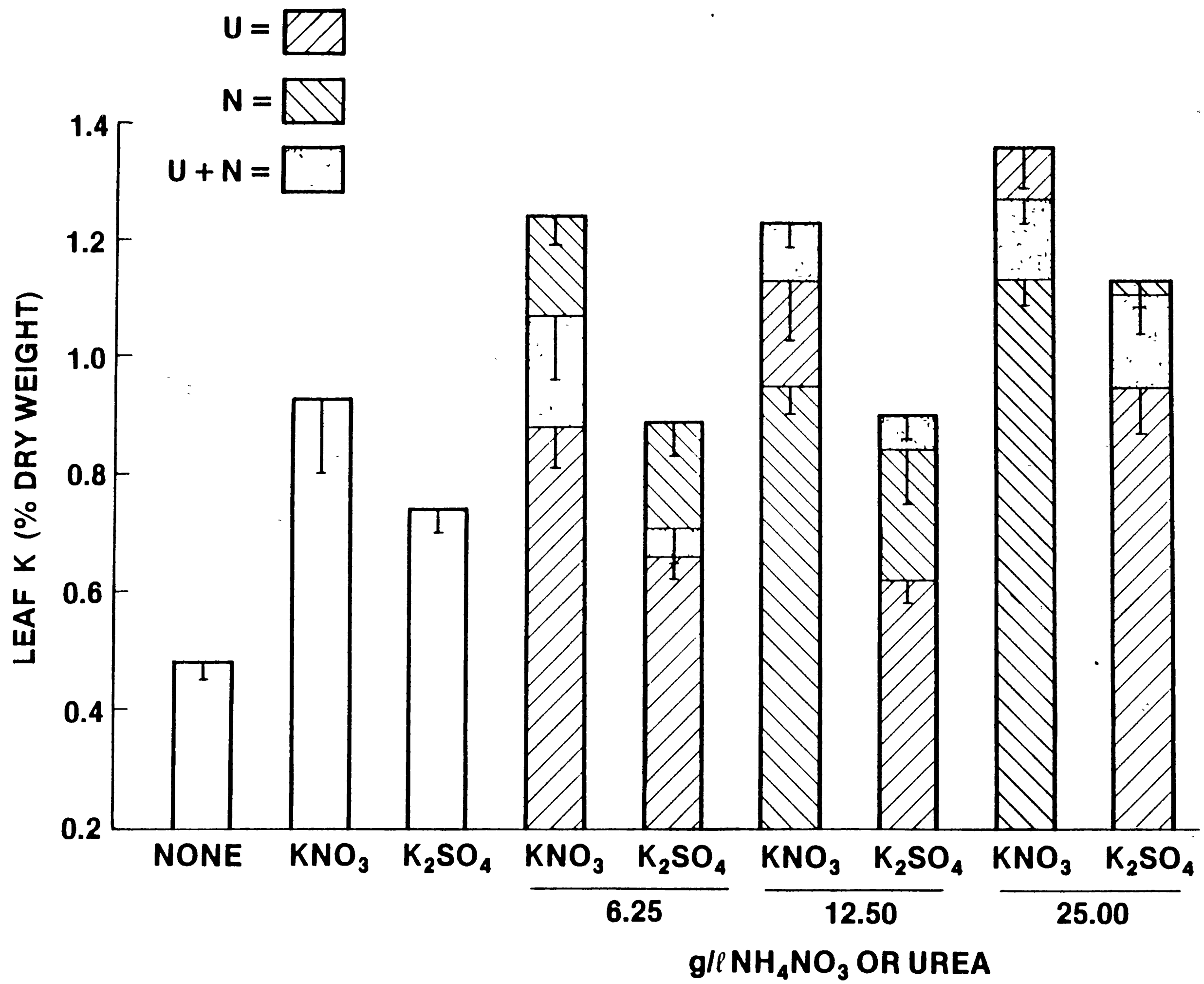
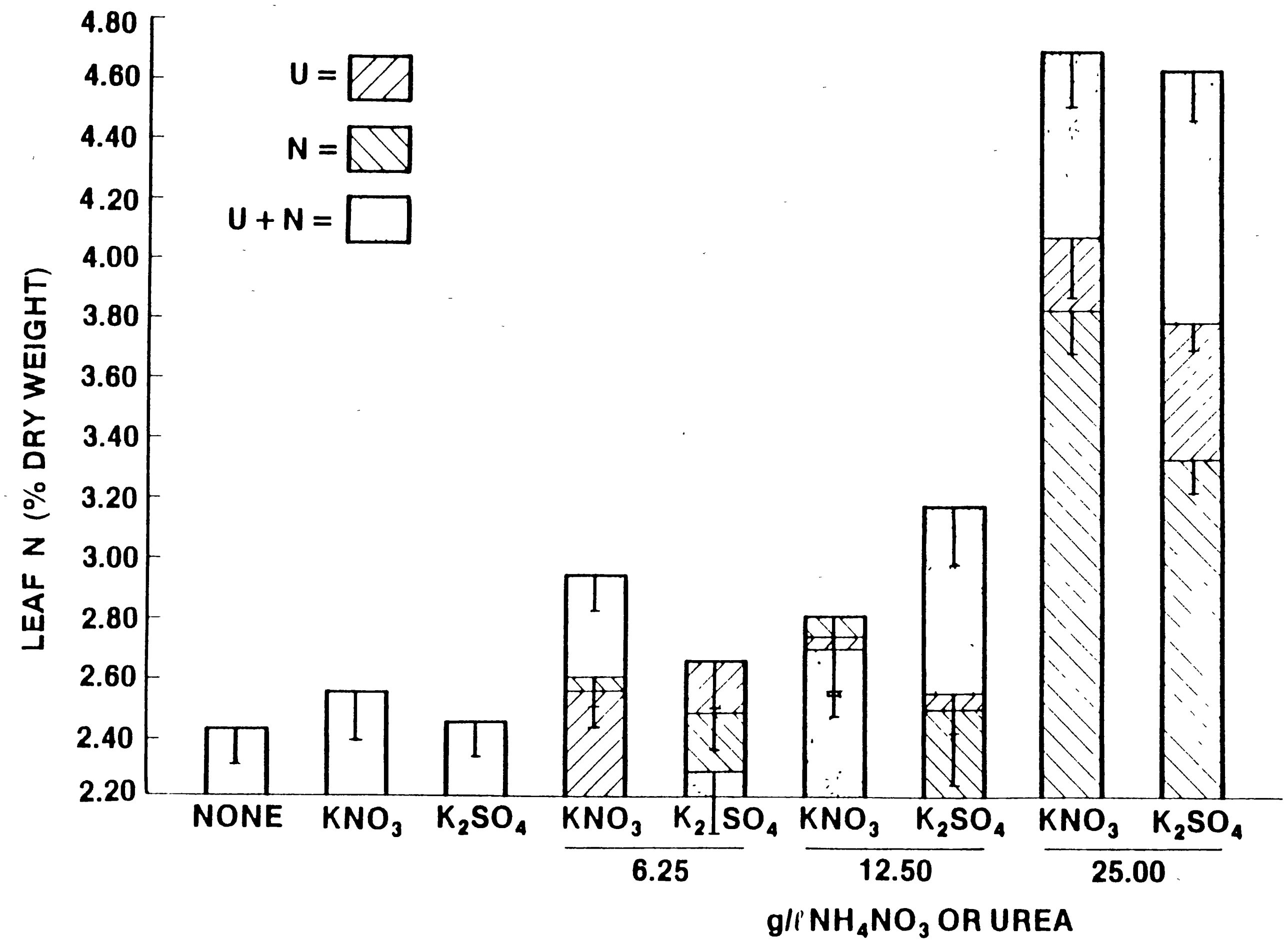

U =
N =
U + N =
LEAF K (% DRY WEIGHT)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
NONE
KNO_3
K_2SO_4
KNO_3
K_2SO_4
KNO_3
K_2SO_4
KNO_3
K_2SO_4
6.25
12.50
25.00
g/ℓ NH_4NO_3 OR UREA

Fig. 2. The influence of K source, NH_4NO_3 and urea on leaf N concentration. KNO_3 25.3g/l; K_2SO_4 21.8 g/l. Vertical bars indicate the standard error of the mean.


U =
N =
U + N =
LEAF N (% DRY WEIGHT)
4.80
4.60
4.40
4.20
4.00
3.80
3.60
3.40
3.20
3.00
2.80
2.60
2.40
2.20
NONE
KNO_3
K_2SO_4
KNO_3
K_2SO_4
KNO_3
K_2SO_4
KNO_3
K_2SO_4
6.25
12.50
25.00
g/ℓ NH_4NO_3 OR UREA

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APPENDICES

APPENDIX A

SEASONAL ELEMENTAL CONCENTRATIONS STUDIES

TABLE I

Seasonal Changes in the Concentration of N, P, K, Ca, Mg, Zn, Fe, and Mn Per Fruit

Element	Date									
	6/9	6/25	7/7	7/21	8/3	8/18	8/28	9/15	9/29	10/15
(% Dry Weight)										
N	1.96a	1.65b	1.31c	1.15d	1.00e	.92f	.78g	.80g	.87f	.87f
P	.27a	.26a	.21b	.18c	.18cd	.16cd	.15d	.10e	.11e	.18cd
K	.99d	1.07d	1.20c	1.37b	1.35b	1.34b	1.32b	1.33b	1.30b	1.54a
Ca	1.43a	1.18b	.92c	.74d	.59e	.49f	.41g	.33h	.31h	.21i
Mg	.69a	.57b	.51c	.38d	.32e	.25f	.21g	.41h	.15h	.14h
(μg/g)										
Zn	83a	92b	70c	44de	46d	37ef	33fg	32fg	29fg	28g
Fe	55b	33c	30cd	21de	26cde	19e	18e	72a	50b	18e
Mn	448a	403a	339b	270c	248cd	194de	176ef	128fg	122fg	98g

Means followed by the same letter are not significant at the 5% level by Duncan's Multiple Range Test.

TABLE II

Seasonal Changes in the Elemental Concentration of the Shuck, Shell, and Kernel

Fruit Part	9/15	9/29	10/15	9/15	9/29	10/15
	N (% Dry Weight)			P (% Dry Weight)		
Kernel	1.45	1.52	1.34	.22	.23	.31
Shell	.24	.26	.26	.03	.03	.04
Shuck	.83	.73	.63	.08	.07	.10
	K (% Dry Weight)			Ca (% Dry Weight)		
Kernel	.91	.51	.42	.13	.10	.05
Shell	.17	.16	.12	.43	.45	.46
Shuck	2.52	2.86	4.27	.38	.38	.36
	Mg (% Dry Weight			Zn (μg/g)		
Kernel	.18	.13	.11	43	37	33
Shell	.06	.05	.03	5.4	4.8	4.8
Shuck	.23	.24	.27	46	39	38
	Fe (μg/g)			Mn (μg/g)		
Kernel	46	25	23	130	116	83
Shell	20	16	6	59	61	47
Shuck	130	93	21	166	189	157
	Dry Weight (g)					
Kernel	1.752	2.888	4.368			
Shell	2.180	2.344	2.224			
Shuck	2.768	3.196	2.972			

APPENDIX B

FOLIAR APPLICATIONS STUDIES

TABLE III

Common Equivalent Conversions Associated with Foliar K Applications

Molarity	G/L	LBS/100 GAL		Solution Concentration	G K/L
K_2SO_4	g/l	kg/.38kl	lbs/100 gal	%	g k/l
.03125M	5.4g/l	2.04kg	4.5 lbs	.54%	2.42g
.0625	10.9	4.12	9.09	1.09	4.88
.125	21.8	8.26	18.2	2.18	9.78
.25	43.6	16.51	36.4	4.35	19.53
.50	87.1	32.98	72.7	8.70	39.02
1.0	174.3	65.95	145.4	17.40	78.09
KNO_3					
.25M	12.6g/l	4.81kg	10.6 lbs	1.27%	4.88g
.50M	25.3	9.57	21.1	2.93	9.78
Urea					
.1042M	6.25g/l	2.36kg	5.2 lbs	0.623%	
.2084	12.50	4.71	10.4	1.25	
.4168	25.00	9.43	20.8	2.50	
NH_4NO_3					
.0781M	6.25g/l	2.36	5.2 lbs	0.623%	
.15625	12.50	4.72	10.4	1.25	
.3125	25.00	9.44	20.8	2.50	

Gram Molecular Weight

K_2SO_4	174.3g/l is 1.0M (174.26)
KNO_3	101.1g/l is 1.0M
Urea	60g/l is 1.0M (60.1)
NH_4NO_3	80g/l is 1.0M

VITA

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Master of Science

Thesis: STUDIES ON THE INFLUENCE OF FRUIT DEVELOPMENT ON SEASONAL ELEMENTAL CONCENTRATION AND DISTRIBUTION IN FRUIT AND LEAVES OF PECAN AND THE INFLUENCE OF FOLIAR K APPLICATIONS ON PECAN SEEDLINGS

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